A STRANGE SIGHT

It was a warm October morning in the year 1800. A young boy led his cow along country roads in Banaswadi, Bangalore, while his dog scampered a few metres ahead. Suddenly, the trio stumbled upon a very strange sight.

The boy stared. The dog stared. Even the cow stared.

In a nearby field, men lugged wooden boxes and iron bars, planting them into the ground. Another group hauled out thick, heavy iron chains. Some other men peered into boxes and pointed towards distances for no purpose that the boy could fathom. Inspecting the instruments and quietly issuing orders, was a tall, well-built Englishman with reddish hair.

The boy scratched his head. *What were they doing? Were they building something? Were they digging a well? Or was that . . . a weapon of some sort?*

He decided it was safest to make himself scarce.

The boy had stumbled upon the beginnings of the Great Trigonometrical Survey of India, one of the largest and most impressive scientific feats in history.

The Great Trigonometrical Survey of India (GTS) was an ambitious project to carry out the survey of the Indian subcontinent with scientific precision. It began in 1802 and took nearly 100 years to complete.

WHAT WAS THE POINT OF THIS SURVEY?

By the late 1700s, the East India Company (EIC) had taken control over large parts of the Indian subcontinent.

EAST INDIA COMPANY/EIC/THE BRITISH

The East India Company (EIC) was an English (later British) trading company established in 1600 to conduct trade with South Asia, East Asia and Southeast Asia. Over time, it expanded its influence and gradually gained control over large parts of India and other regions in Asia, leading to their eventual colonization. In 1858, following the Indian Rebellion of 1857, the British Crown took direct control of these territories, dissolving the Company's rule.

In this book, when we refer to the Company, EIC or the British, we specifically mean the East India Company unless otherwise stated.

As the East India Company (EIC) took over more land, they realized there weren't any accurate maps of these places.

So, when William Lambton, an English infantry officer with experience in surveying, proposed to the authorities that an accurate map of India could be made using a precise technique called triangulation, the EIC approved it promptly.

SURVEY: In this book, a survey refers to a project that studies and records the land and its features to create a map. When written with a capital S, Survey refers specifically to the Great Trigonometrical Survey.

WHAT DID THE GREAT TRIGONOMETRICAL SURVEY DO?

The Great Trigonometrical Survey (GTS) was the most advanced survey of its kind in the Indian subcontinent at the time—and the largest in the world! It mapped the entire subcontinent and even measured the Himalayan peaks, proving for the first time that Mt Everest is the tallest mountain in the world. Before this, people thought the highest mountain was somewhere in South America!

But that's not all—the Survey made a huge impact on science and technology. It helped scientists figure out exactly how curved the Earth's surface is. Sounds unbelievable, right? How could a few triangles help map an entire land and even measure the Earth's shape?

Well, read on, and you'll find out!

THE AUDACITY OF THIS ENDEAVOUR

The Great Trigonometrical Survey (GTS) lasted nearly a hundred years and was led by several men, including William Lambton, George Everest and Andrew Waugh. But it wasn't just them—thousands of people worked on this massive project.

They did it all using just a few simple (but heavy!) instruments, which they had to lug across mountains, forests and rivers. Their work involved thousands of calculations. Imagine doing them all without computers or even calculators!

The surveyors faced all kinds of challenges—malaria, diarrhoea, heavy monsoons, dense jungles, wild animals, injuries and even distrust from locals. Yet, they kept going, mapping the entire country from south to north.

In this book, you'll discover some of these amazing stories and the incredible people behind them. You'll also learn the simple science and maths they used, try your own mini survey, impress your friends with cool astronomical tricks and even find hidden relics of this grand project around you!

THEODOLITE: A powerful telescope used in surveying to measure angles between distant objects.

TRIANGLES ARE FASCINATING SHAPES!

Before we go further, let's understand what triangulation is, since we're going to talk about it a whole lot in this book.

Triangulation is a technique that uses the amazing characteristics of a simple triangle. You know a triangle has three points, three sides and three angles, right? Here's something cool: if you know the length of one side and two of the angles, you can calculate the lengths of the other two sides—without actually measuring them!

Sounds confusing? Let's take an example.

Imagine you're in a park, and your friend is standing a few steps away from you. There's a dog sitting some distance away from both of you.

'The dog is closer to me,' you say.

'No, I think the dog is closer to me,' says your friend.

Who's right?

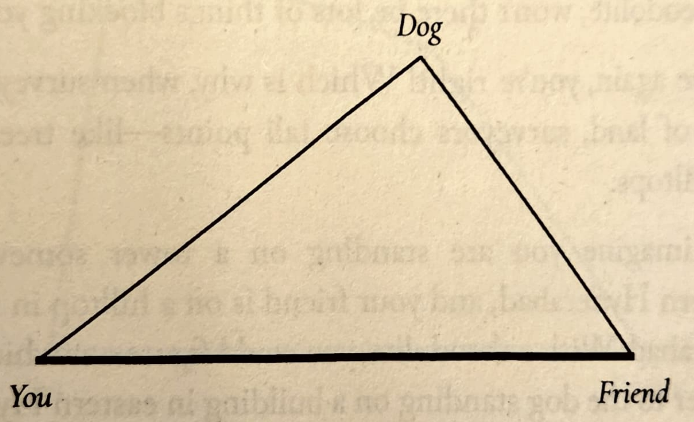
The easiest way to find out is to take a tape measure and check the distance between you and the dog and your friend and the dog. Simple!

But what if the dog looks a little scary? Maybe it's growling, and you don't want to go near it.

Good news—you don't have to! You have a special tool that measures angles. (No, not a protractor like the one in your geometry box—that works well with paper and pencil, but not for this job.) This clever device is called a theodolite. We'll talk more about it soon, but for now, just imagine something that looks like a telescope.

Now, you, your friend and the dog make up three points of a triangle. Are you with me so far?

Take a stick and draw a line on the ground between you and your friend. Then, use your tape measure to find the distance between the two of you. This will be the length of one side of the triangle.



Now, go back to your spot, hold the theodolite, and look through its eyepiece. Turn it until you can see the dog through the eyepiece. Note down the measurement that the theodolite displays in this position. This measurement is one angle of the imaginary triangle that connects you, your friend and the dog.

Your friend does the same thing from their point and notes down their own measurement, which gives the second angle. So far so good!

Now, using just the distance between you and your friend and the two angles you both measured, you can calculate how far each of you is from the dog! All you need is a simple formula and a calculator.

Wait! I hear you saying. All these angles and calculations? There must be an easier way to figure out who's closer to the dog!

You are absolutely right. When we are talking about small distances like your street, or a park or your school playground, there are definitely other options.

But when you're dealing with huge distances—like 40 kilometres or even 100 kilometres—you'll be really thankful for a theodolite, trust me!

I know what you're thinking. This sounds useful for long distances, but how can you even see that far? If you look through the theodolite, won't there be lots of things blocking your view?

Once again, you're right! Which is why, when surveying large tracts of land, surveyors choose tall points—like trees, towers and hilltops.

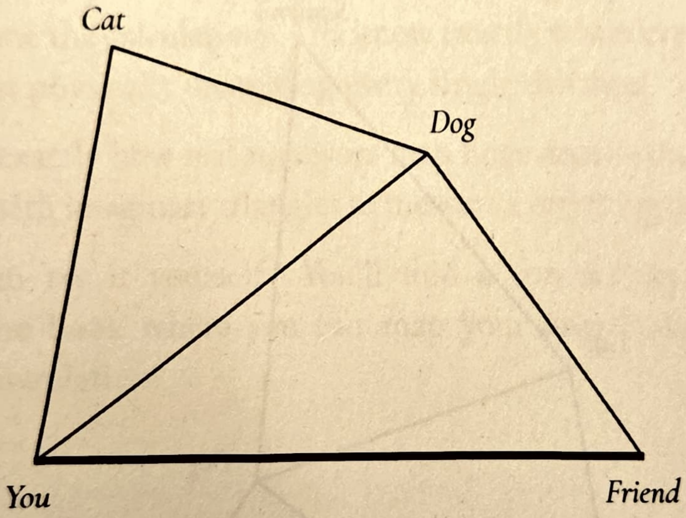
So, imagine you are standing on a tower somewhere in southern Hyderabad, and your friend is on a hilltop in northern Hyderabad. With a theodolite, you could figure out which of you is closer to the dog standing on a building in eastern Hyderabad. Could you do that with a tape measure? Nope!

For these triangle calculations, we use the principles of **trigonometry**. It is a branch of mathematics that deals with how the sides and angles of a triangle are related to each other. If you haven't learned trigonometry yet and want to understand how triangulation works and the formulae used, you'll find an explanation at the end of the book. But don't worry! You don't need to know trigonometry to enjoy the rest of this book. All you need to know is that triangles are amazing shapes!

Okay, so why is all this important in land mapping and surveying?

Triangulation is one of the most accurate ways to find the exact location of points across huge areas. How? By mapping a network of triangles!

Remember the example with you, your friend and the dog in the park? Now, let's add a cat to the scene—watching you both lazily. Is the cat closer to you or to the dog? Let's find out!



Let's imagine another triangle—this time between you, the dog and the cat.

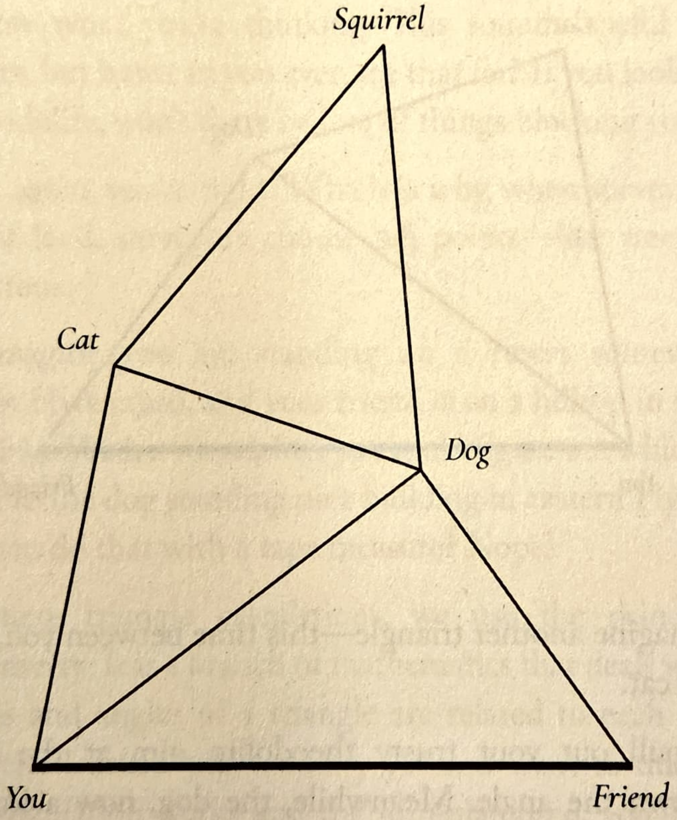
You pull out your trusty theodolite, aim at the cat, and note down the angle. Meanwhile, the dog, now a little more comfortable around you, wags its tail and lets you stand beside it to measure the angle between it and the cat.

With just these numbers, you can now figure out exactly how far the cat is from you. And guess what? You can even tell how far the dog is from the cat!

But wait! What's that rustling in the distance? A squirrel is watching this whole scene unfold from under a tree. Now you're curious—how far is the squirrel from the cat and the dog?

Using the same trick, you measure the angles to the squirrel from the dog and the cat, and you can figure out exactly how far it is!

Pretty cool, right? This is how surveyors map entire landscapes—one triangle at a time!



Do you see what we are doing here?

We're creating a network of triangles across the park, and through that, we're mapping the park and getting to know it better! And here's the coolest part—apart from the first line you drew between you and your friend, you haven't actually drawn anything on the ground.

These triangles? They're all imaginary!

If you looked down from a drone flying high above, you'd only see one real line—the one between you and your friend. That's called the **baseline**. The drone can see you, your friend, the dog, the cat and the squirrel—but not a single triangle!

And yet, on your piece of paper, these triangles are very real. You've done the calculations. You know exactly where everything is, without physically measuring every single distance!

This is exactly how real surveyors map huge areas—they cover the land with imaginary triangles to measure everything precisely.

Want to try it yourself? You'll find a fun activity at the end of the book where you can map your own living room using triangulation!

MAPS AND SURVEYS: WHY BOTHER?

Have you ever played a game of hide-and-seek or running-and-catching in a place that's new to you? Maybe a small park, an apartment complex or a street in a new neighbourhood?

At first, everything feels strange and unfamiliar. But your friends, who already know the place well, have jumped right into the game. So, you dive in too, trying to keep up. But you quickly realize they have the advantage. They know the best hiding spots, the fastest escape routes, and you're left scrambling.

But then, you come back a few more times. You play a few more games. Slowly, you start figuring things out. You begin to see the place in your mind—the best spots to hide, the tricky tree root that could trip you up, the perfect bush that will keep you out of sight.

Now, you're on equal footing with your friends. You're no longer lost.

If you want to be in control of a place, you need to know it well. And for that, you need a map—even if it's just a mental map inside your head. For larger places, like a new school or an unfamiliar neighbourhood, you might need a paper map or a map on your phone.

We now live in a world that is completely mapped out. GPS and Google Earth are so much a part of our lives that it is actually difficult for us to get truly lost. So it is very hard for us to imagine a world in which nothing was known about large regions of the planet.

But the unknown has always been attractive. The mystery! The adventure! No wonder explorers set out across uncharted lands, eager to discover what lay beyond. They even sailed across unknown seas—back when some people still believed the world was flat, and that if a ship went too far, it might fall off the edge into nothingness!

As these brave explorers travelled, they made maps. They estimated distances based on the hours they had walked or ridden and determined directions using a compass or the position of the Sun. As you can imagine, these maps were rough and not always accurate. They created them as references for their own journeys, to guide those who came after them and to report back to the superiors who had funded their expeditions. After all, their sponsors wanted to know how their money was being spent!

India, with its wealth of spices, textiles and other valuable goods, was a highly attractive destination for traders from around the world. Merchants who travelled to India also made maps. Though these maps were basic and often inaccurate, they were still better than nothing—and were more expensive than gold.

When European countries began colonising lands unknown to them, they had a pressing need for maps. They could only take control and govern these territories if they knew the land well—its resources, riches and strategic advantages—all of which they intended to exploit. They also needed maps to defend themselves against local rulers who resisted, fighting to protect their homeland. In addition, maps helped them safeguard their newly acquired lands from rival colonisers who were also seeking wealth and power in the same regions.

LOCAL TRADITIONS OF MAP-MAKING

People were probably making maps in India long before the British arrived. The problem is we have very few of them left. One of the oldest known maps in India may be a **rock painting in Madhya Pradesh**, estimated to be several thousand years old. Some historians believe it is a depiction of a river with water plants and fish.

Another very old example is a small, 1,800-year-old piece of a broken clay pot found in Andhra Pradesh. It has a drawing that some scholars believe is a plan of a Buddhist monastery.

About a thousand years ago, architects worked on a huge temple called the Bhojeshwar temple, near Bhopal in Madhya Pradesh. The temple was never completed, but we can still see the plans they drew for the temple on the rocks nearby.

There are also **references to maps in ancient stories and plays**, showing that maps were certainly being made, even if we haven't yet found many surviving examples. For instance, a play from the 1400s mentions a map of Champaner Fort in Gujarat, printed on cloth.

Some maps made for religious reasons have survived. For example, we have some old maps made for pilgrims that were painted on cloth. They show temples and also other recognisable features such as rivers and mountains.

In the seventeenth and eighteenth centuries, the Marathas made maps of forts, coastlines, and routes. Interestingly, their maps had East at the top, unlike modern maps, which usually have North at the top. A map from South India in the early eighteenth century or earlier was even drawn with South at the top.

These maps reflected mapping traditions very different from the modern styles we use today.

MAPMAKING IN BRITISH INDIA

As the British gradually took control of India's administration, they became desperate for maps. At first, these were needed for military purposes, but soon, the focus shifted to collecting revenue, especially taxes—or, to put it more bluntly, to loot the land. The first large-scale survey of India was conducted by James Rennell, who is often called the Father of Indian Geography. In 1782, he created the *Map of Hindoostan* using route surveys, a common method Britain used to map its colonies in the eighteenth century.

A route survey involved travelling along a road, river or track and measuring the distance and direction of the route taken.

Rennell measured distances using the perambulator—a wheel with a counter attached. As it was rolled along the ground, it recorded the number of revolutions, and from that, the distance could be calculated. Neat, huh! He used a compass to determine directions. At intervals, he checked the latitude and longitude of the place through astronomical observations using the positions of the stars, which is explained at the end of this chapter.

Then he put all these observations into a grid of latitudes and longitudes to make a map. Okay, but why into a grid, you ask. Remember the dog, the cat, the squirrel and your friend? Imagine they were standing very far apart and you had to tell your friend how to get to the squirrel. You might say something like, 'Go close to the tree and then walk a bit.' Or, 'Walk up to the telephone pole and then go right ten paces.'

See how you need reference points to help someone find their way? That's exactly what the grid of latitudes and longitudes does! Instead of using a tree or a telephone pole, you can pinpoint locations using a global grid system.

In fact, this grid system dates back to the third century BCE—that's over 2,200 years ago! It was developed by Eratosthenes, one of those genius, super-smart old Greek scholars with a long name. He was a whiz at maths, physics, astronomy, poetry, geography and even music!

LATITUDES: Also known as parallels, latitudes are imaginary lines that divide the Earth and run east to west around the Earth. They are parallel to the Equator, which is denoted by zero degrees and divides the Earth into northern and southern hemispheres. Latitudes measure distance north or south of the equator in degrees.

LONGITUDES: Also called meridians, longitudes are imaginary lines that divide the Earth and run north to south from pole to pole. They measure distance east or west of the Prime Meridian, which runs through Greenwich in England, and is denoted as zero degrees. Longitudes are measured in degrees east or west.

DEGREES, MINUTES AND SECONDS: Ever wondered how we pinpoint exact locations on Earth? It all comes down to degrees, minutes and seconds—the secret code of latitude and longitude!

The Earth is divided into 360 degrees (°) of longitude—180° east of the Prime Meridian and 180° west of it. Latitude works the same way, but there are only 180 degrees (°) of latitude—90° north of the equator and 90° south of it.

But wait—degrees alone aren't precise enough! So, each degree is broken into 60 minutes (′), and each minute is further divided into 60 seconds (″).

Let's say you ask your friend, 'Where are you?' and they respond, '12° 55′ 30.92736″ N · 77° 35′ 37.11588″ E.'

Sounds fancy, right? What they're really telling you is their exact location on Earth, using latitude and longitude—just like how GPS finds places! So, next time you see a set of coordinates, you'll know it's not just a bunch of numbers—it's a map code for a real place!

Anyway, back to Rennell. His route survey was quick and covered large distances efficiently. But there was a problem—it wasn't very accurate. The instruments he used lacked precision, and his latitude and longitude measurements had errors. This meant his maps provided only a rough idea of places and distances.

A trigonometrical survey using triangulation, on the other hand, was a far more accurate way to create maps. And this precise method became the foundation of the Great Trigonometrical Survey.

TRIGONOMETRICAL SURVEYS

Since you've already read about triangulation, you'll understand why it is a much better method for surveying than a route survey. A trigonometrical survey, which uses triangulation to map the land, works by creating a network of interconnected triangles across the area until the entire region is covered. The biggest advantage of this method is that it's very accurate.

Triangulation is also important in geodesy, the science of measuring the Earth's shape—but we'll get to that later.

Despite its accuracy, triangulation has its challenges. It is slow and requires careful planning. Bad weather, like rain or haze, can disrupt the process. The calculations involved are complex and cumbersome. It also relies on simple yet extremely delicate instruments and needs a team of highly skilled professionals, making it expensive.

Trigonometrical surveys were being recognised in the late 1700s as the most accurate, modern and scientific method of mapping. Britain had already started on a trigonometrical survey on their own lands in the 1790s. Now India needed one.

And the person who would convince the higher-ups to invest in this immense project was a gentle, unlikely man.

ASTRONOMICAL OBSERVATIONS: USING THE STARS TO MAP YOUR LOCATION

• • •

Do you know that the way your night sky looks to you is not necessarily the way it looks to someone in another part of the world? The stars you see and their positions change depending on where you are. Raichur, a city in Karnataka, sits at 16°N latitude. Guess what? Timbuktu, a famous city in Mali, is also at 16°N latitude! But there's one big difference—they are on different longitudes, meaning they're in different time zones.

Raichur is ahead of Timbuktu by 5 hours and 30 minutes.

Now, imagine this: It's 10 p.m. in Timbuktu. A kid there looks up at the night sky. At that exact moment, it's 3:30 a.m. in Raichur, and a kid there is also looking up. But even though they are both staring up at the sky at the exact same moment, the stars appear to them to be in different positions!

Fast forward five and a half hours—now it's 3:30 a.m. in Timbuktu. If the same kid in Mali looks up, they will see the stars exactly as the kid in Raichur had seen them earlier! But by this time, it's already 9 a.m. in India, and the Raichur kid is at school, probably sleepy from waking up so early to watch the stars.

The position of the stars in the sky can tell us where we are.

A long time ago, sailors used the stars to find their way across the ocean when there were no roads, maps or GPS to guide them. By looking at where the stars were in the sky, they could figure out their latitude and longitude.

LATITUDE MEASUREMENTS

In the Northern Hemisphere, one of the easiest ways to find your latitude is by using the North Star, also called *dhruvatara* in India.

The North Star is special because it sits almost perfectly in line with Earth's axis of rotation. That means, unlike other stars that move across the sky, the North Star stays fixed in one spot. This is why it's also called the Pole Star or Polaris.

Here's how it works:

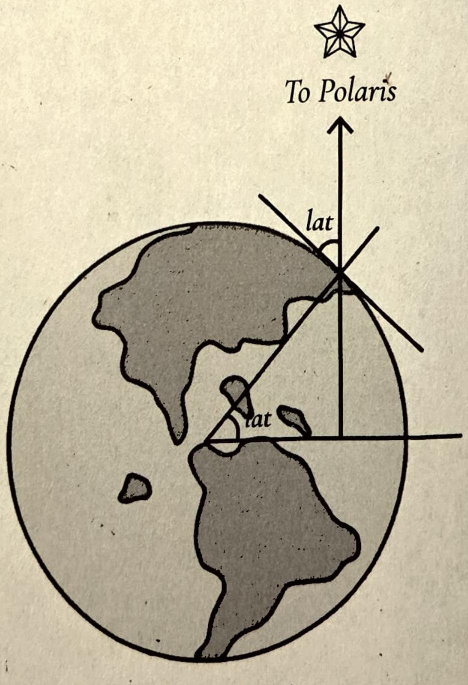
If you stand at the North Pole, the North Star will be directly overhead—so it's 'altitude' is said to be 90° above the horizon.

If you stand at the Equator, the North Star will be right at the horizon—that's 0°.

Anywhere in between? The angle of the North Star above the horizon tells you your latitude.

You can measure this angle using a sextant or even just your hand (we'll show you how later in this book).

The North Star is a great guide, but you can do this with any star. Every star has a highest point in the sky, called its zenith, and this highest point changes depending on where you are. If you know what time a particular star reaches its zenith, you can use an almanac (a special calendar with star positions) to figure out your latitude—just like ancient explorers did.



Finding Latitude

LONGITUDE MEASUREMENTS

Did you know that you can figure out your longitude just by checking the time? Longitude is measured based on the time at Greenwich Meridian (0° longitude)—the starting point for all time zones.

Here's how it works:

A watch or chronometer keeps the constant time at Greenwich.

Local time is measured by checking the position of the Sun at noon using a sextant.

The Earth is 360° around and takes 24 hours to complete one rotation. So, every 15° of longitude = 1 hour (since 360 ÷ 24 = 15).

This means:

If you move 15° east from Greenwich, local time is 1 hour ahead.

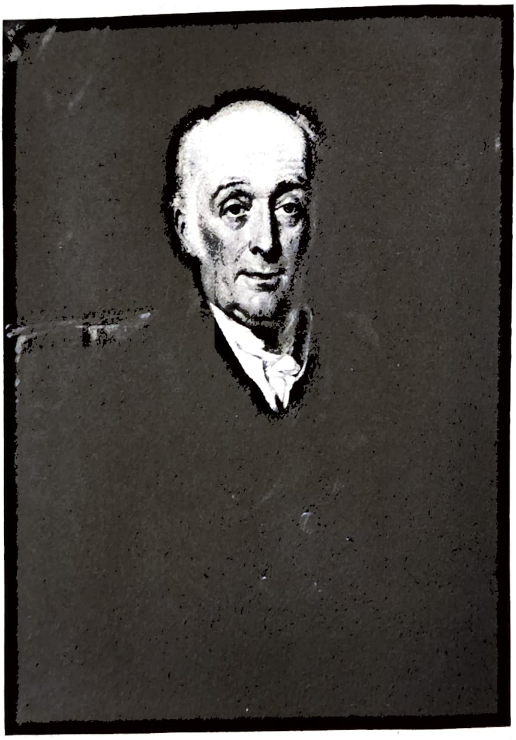
If you move 15° west, local time is 1 hour behind.

So, by comparing Greenwich time with local time, you can calculate your longitude.

Instead of using the Sun at noon, surveyors from the Great Trigonometrical Survey (GTS) used stars at night to determine longitude more precisely. Imagine looking up at the night sky and unlocking a map of the world!

THE MAN WHO MADE IT ALL HAPPEN

A SHY GENIUS



Portrait of William Lambton

William Lambton was born in . . . well, to tell you the truth, no one really knows. In fact, we know very little about the man who started the humongous country-wide science project that became the GTS. The reclusive Lambton did not like talking about himself. We can guess his birth year thanks only to a king's whim. At a dinner hosted by the Raja of Coorg (now Kodagu) in 1803, guests were asked to declare when they were born. Everyone did so—except Lambton. Later, he asked a friend, 'What would you have said if I had claimed to be fifty?' The friend did some quick calculations: the party was in 1803, which meant Lambton was born in 1753. And that is all we know about his age.

He was born in Durham . . . or was it Yorkshire? But he stayed in Darlington, right? Well, we know he was born and studied somewhere in England. His family was probably not very rich. And we know for sure he loved mathematics.

He also loved astronomy, so much so that it once made him act very foolishly. When he was in his early twenties (or maybe thirties!) and serving in Canada as a soldier in the English army, he looked at a solar eclipse through the telescope of a theodolite. Uh oh! The result? A permanently damaged left eye.

Incidentally, he wasn't the first scientist to do something foolish during an eclipse. Isaac Newton had once tried to observe an eclipse with a mirror and ended up blind for three days. This wasn't the only thing he and Newton had in common, as we'll see shortly.

In the 1790s, Lambton's regiment fought in the fourth Anglo-Mysore war between the British and Tipu Sultan. In fact, Lambton's stargazing played a small role in that war. Late one night in April 1799, Lambton and a few other soldiers were led by General David Baird to scout an areca plantation near Srirangapatna where Tipu's rocketmen were believed to have set up a small defensive post. After scouring the area and finding neither rocketmen nor any other men, Baird decided it was time to return to their camp. He set off and the other soldiers followed. But Lambton felt something was amiss. He looked up, found the constellation of the Great Bear, found the Pole Star and realised they were marching North, right towards Tipu's encampment!

When he told General Baird, the senior officer responded that he knew well enough what he was about without having to consult the stars, thank you very much. Hardly had he spoken when they ran into an advance party of Tipu's army. The General hastily caught a firefly, held it up to his compass and realised Lambton was right: they were indeed heading North. The soldiers did an about turn and marched back to the safety of their own camp. Exactly a month later, General Baird led the successful British assault against Tipu Sultan in which he was defeated and killed.

Lambton's star turn may have changed the course of history, but he was not one to talk about it. He was happiest when behind a telescope or solving equations or working on his theodolite. And while he was usually awkward at parties, he was friendly, genial and compassionate with his co-workers. Not surprisingly, his colleagues and juniors were all fiercely fond of him.

Lambton had a curiosity about all things scientific. He was especially interested in geodesy, which is a field of science devoted to figuring out the shape of the Earth (who knew there was such a thing!). Lambton had developed this fascination for geodesy while in his previous job surveying in Canada. He followed the latest developments in this field very closely. Of course, he was also interested, very interested, in making a map.

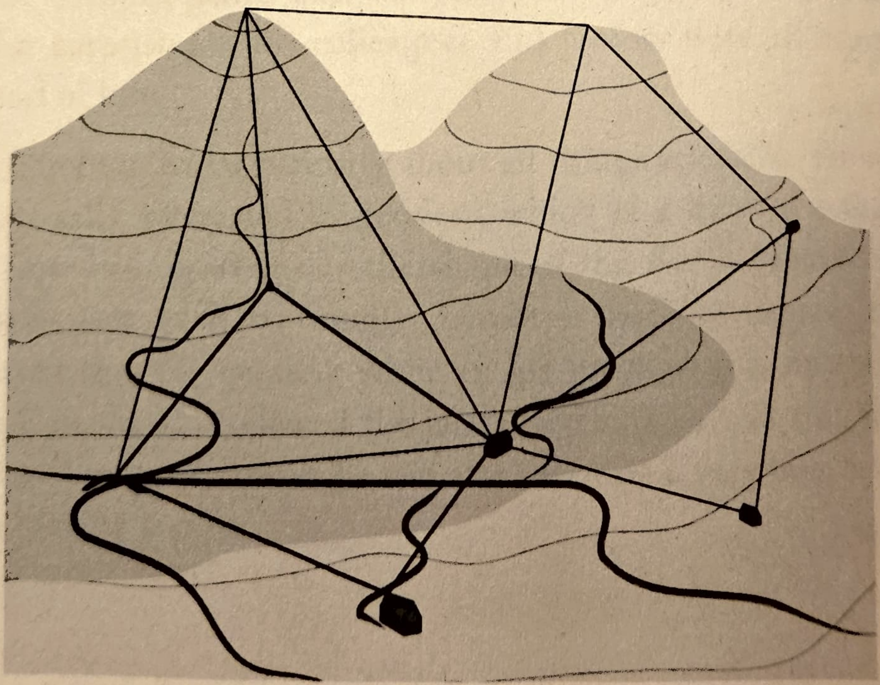
Lambton realised that using triangulation, he could do both of these at once.

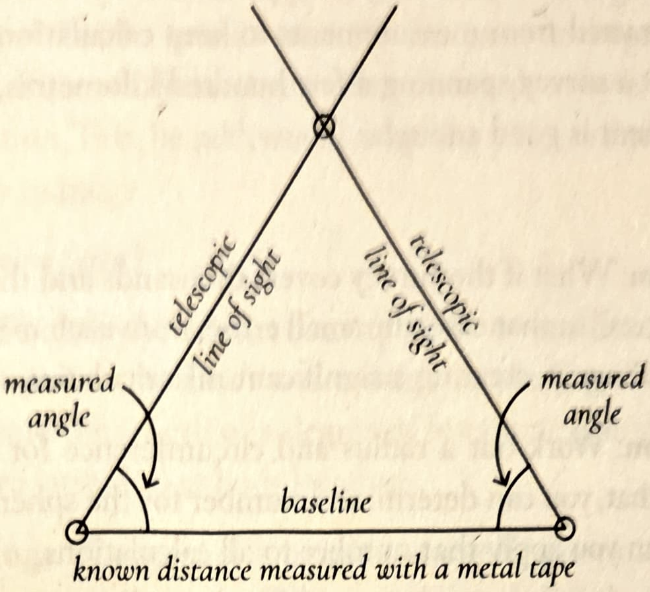
With triangulation, his survey wouldn't just be a map; it would also be a measurement. It wouldn't just be a feat of geography but also of geodesy.

GEODESY

Geodesy is the study of the Earth's shape.

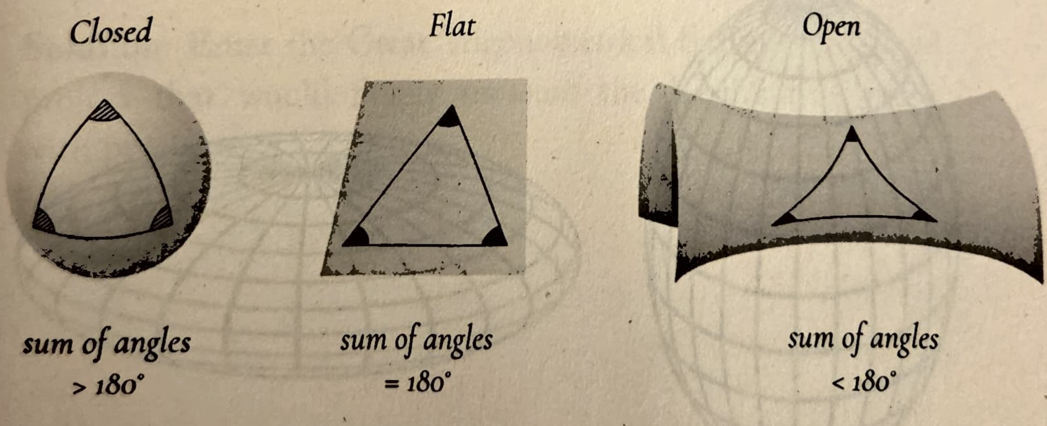
As we've seen before, triangulation is two-dimensional. It assumes that all measurements are done on a level surface, a plane. But the Earth's surface has bumps and dips. Triangulation treats those highs and lows as points in vertical triangles, as shown in the illustration. And measurements can continue as if it's all still a flat surface.




telescopic
line of sight
telescopic
line of sight
measured
angle
measured
angle
baseline
known distance measured with a metal tape

But here's the problem: the Earth's surface is curved.

In a regular triangle, the angles always add up to 180 degrees. But when a triangle is drawn on a curved surface, its angles open up slightly. This means the total of the angles now add up to more than 180 degrees.


Closed
Flat
Open
sum of angles
> 180°
sum of angles
= 180°
sum of angles
< 180°

Solution: This difference in measurement is known as 'spherical excess'. Even if we have only an approximate value for this, it can be subtracted from measurements to keep calculations accurate. And for a survey spanning a few hundred kilometres, this small adjustment is good enough.

But . . .

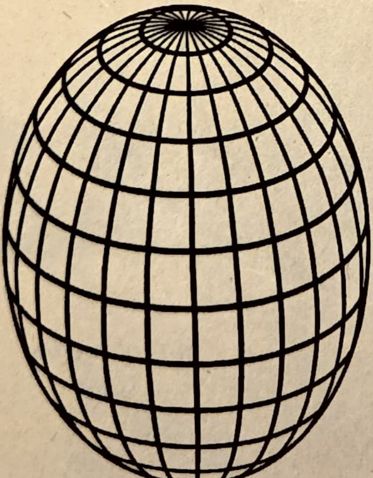
Problem: What if the survey covers thousands and thousands of kilometres? In that case, the small errors from each measurement start adding up, creating a significant miscalculation.

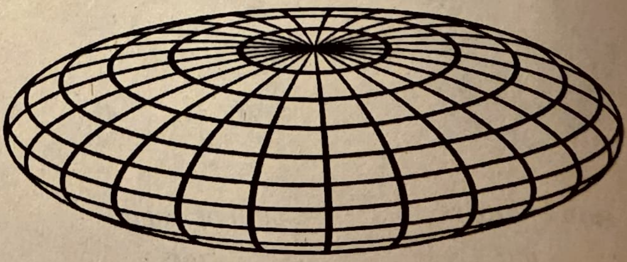
Solution: Work out a radius and circumference for the Earth. Using that, you can determine a number for the spherical excess, and then you apply that number to all calculations.

But . . .

Problem: The Earth isn't perfectly round.

So what is its actual shape? Flatter at the sides, like an egg? Or flatter at the top, like a grapefruit? This was a long-standing debate in the world of science and geography—Team Egg versus Team Grapefruit!





In Team Egg, we had several French scientists. Team Grapefruit was led by none other than Isaac Newton, who argued that because the Earth rotates around its axis, it experiences centrifugal force—a force that pushes outward, away from the axis of rotation. This, he said, would cause the poles to flatten and the equator to bulge.

So, who was right?

Solution: To settle the debate, two expeditions were launched in the 1700s—one to the Poles and another to the Equator. Their goal? Measure the length of a degree of longitude (the distance between two latitudes) at both locations.

Their findings: A degree of longitude at the Equator measured 110 kilometres, while at the Poles, it measured slightly more—111 kilometres. This meant that the Earth was more curved at the Equator and flatter at the Poles.

Conclusion: The Earth wasn't an egg after all. It was a grapefruit—or, more precisely, an oblate spheroid.

But . . .

Problem: Just how much flatter were the Poles? And was this shape uniform across the entire planet?

Solution: Enter the Great Trigonometrical Survey—the grand project that would finally measure the Earth's true shape with precision.

LAMBTON'S GRAND PLAN: A LINE ACROSS INDIA

In early 1799, the British defeated their arch enemy, Tipu Sultan, the ruler of Mysore. Tipu had been an unyielding adversary, but with his fall, the British could now roam freely across almost the entire southern peninsula.

For William Lambton, this was the perfect opportunity. With triangulation, he could map the peninsula with unparalleled accuracy. But his ambitions extended beyond cartography—he also wanted to contribute to geodesy, fulfilling what he called 'a desideratum more sublime'—a grand desire.

The Egg versus Grapefruit debate had been resolved by measuring the length of a degree at the Equator and the Poles. But what about the shape of the Earth around the tropics? Now Lambton could 'draw' a line beginning at the southern tip of India and go northward right across the land. In this way, he could measure the length between latitudes at the tropics.

What's more, he wanted to measure the distance between *every* two latitudes on this humongous, unimaginably long line.

By comparing their lengths, he could precisely determine how much the Earth curved at the tropics—a feat no one had yet achieved.

ARC OR ARC OF THE MERIDIAN: In geodesy, an arc or the arc of a meridian is a curve on the Earth's surface that connects two points with the same longitude.

When written with a capital A—as in Arc—it specifically refers to the Great Arc of the Meridian, this particular line across the length of India.

Meridian is simply another word for longitude.

As you can imagine, this concept of geodesy was hard for people to understand. So when Lambton proposed the idea of a trigonometrical survey to the Company, he wrote a lot about triangulation and the importance of accuracy for mapmaking purposes. And then he threw in a couple of lines about the scientific element of geodesy.

The British officials in charge, even if they didn't really get the geodesy part, appreciated that highly accurate maps would certainly have advantages in their policy of further expansion in India. It also helped that several of them knew of Lambton and his work and spoke favourably about him. The result was that the grand, expensive project was approved.

This was why, as the project progressed, Lambton placed great emphasis on accurate measurements, even if it meant a lot of delays and difficulties and repetitions and checking and cross-checking.

The imaginary North-South line across the peninsula came to be known as the Great Arc. It's the longest measurement that has ever been made of Earth.

Spoiler: Lambton's work paid off. International recognition came to him, and geographers and scientists feted and praised him and his work and acknowledged the importance of what he had done.

GETTING THE GEAR TOGETHER

Once Lambton got the go-ahead from the head honchos at the East India Company for his survey, he put in an order for some of the instruments he would need for it. He had kept track of the latest developments in surveying in England, so he had a good idea of the instruments required. Besides, he had also worked as a surveyor in Canada. But some of the equipment he would need wasn't just regular survey stuff but was quite specific to the mammoth task on hand.

It took Lambton nearly two years to acquire everything he needed.

A 100-FOOT STEEL CHAIN

Purpose: To measure the baseline

BASELINE: In surveying, a baseline is an accurately measured line on the ground, from which other lines, and the angles between them are measured.

Remember that line on the ground we drew between you and your friend? That was a baseline.

Some years earlier, a British mission to China had carried with it a steel chain and other astronomical instruments as a gift to the emperor of China. The emperor seemed to be unimpressed and returned it politely. It travelled back with the mission.

China's loss, Lambton's gain. Lambton bought it.

The chain was made of forty bars of steel. Each bar was 76 centimetres long. Brass hinges linked one bar to the next. The entire chain could be folded and packed into a heavy teak chest.

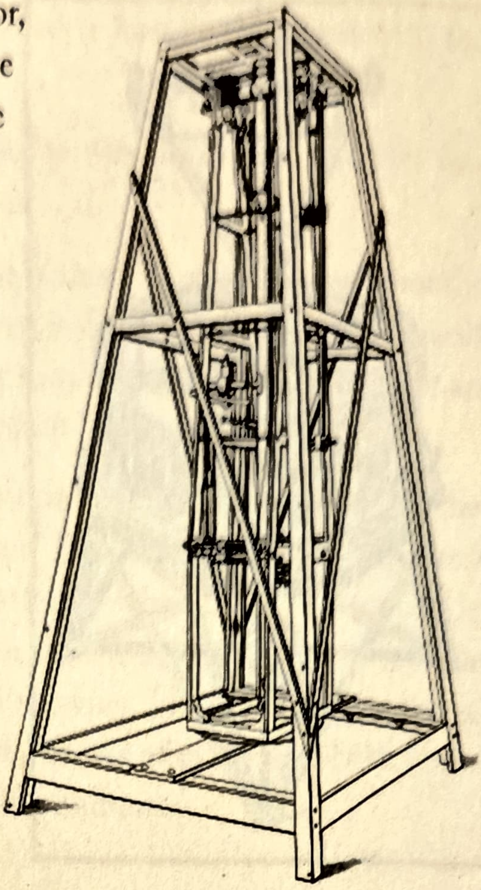
ZENITH SECTOR

Purpose: To measure the latitude of a place

A zenith sector is a telescope designed to point to the sky overhead (the zenith) to make precise measurements of star positions in the sky.

Zenith sector measurements are hard to make. You need to make multiple measurements over many nights. Its parts are affected by factors like iron ore underground. Oh, and the instrument weighed about 500 kilograms.

Lambton's zenith sector, which had also made the trip to China along with the steel chain, was a 1.5 metre zenith sector. He also had a specially constructed observatory tent that he carted around everywhere he went.



Ramsden's Zenith Sector

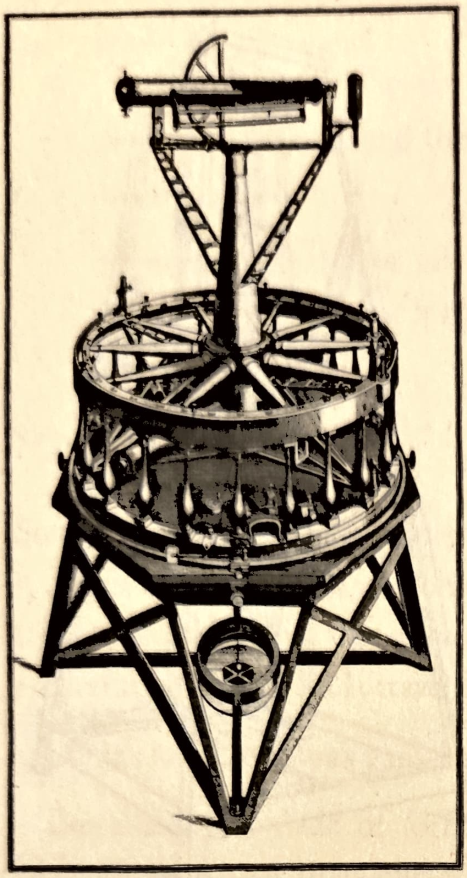
THE GREAT THEODOLITE

Purpose: To measure angles between distant objects

The star of the survey was the theodolite.

A theodolite is a powerful telescope. It is mounted on two rings, one horizontal and one vertical. This allows the scope to move both from side to side and up and down. It can measure angles between distant objects and between objects and the ground.

A theodolite is full of fiddly parts. Spirit levels. Adjusting screws for alignment. Levelling microscopes for reading measurements. So the instrument needs to be stable and precise.



The Great Theodolite

Lambton ordered The Great Theodolite, as the theodolite used in the survey was known, from England. There were only three instruments like this in the entire world at that time.

It was expensive—650 pounds then, which would be about seventy-two lakh rupees today.

It was unwieldy. Its horizontal ring was 91 centimetres in diameter, and its vertical ring 46 centimetres. Each ring had its own microscope. This allowed angles to be measured to the smallest fraction.

And it weighed around 500 kilograms, about half as heavy as an elephant. It required two relay teams of twelve porters each to carry it.

But why did they have to carry it? Couldn't they just use a bullock cart?

They couldn't.

For one, the delicate instrument couldn't withstand the rattling and vibrating of unpaved roads. And then, there were the hills and mountains—places with no roads at all, paved or unpaved.

The porters were specially trained to handle their load with the utmost care and respect.

Much later, a lighter theodolite was developed, but that was after Lambton's time.

Lambton had ordered The Great Theodolite, but months passed, and it still hadn't arrived in India. He was beside himself with worry—it's not even like they had a tracking number or an Airtag to check where on Earth it had gone.

It turned out the ship carrying it had been captured by the French and taken to Mauritius. The French governor unpacked the crate, examined its contents and—thankfully—recognized it as a scientific instrument. Even more thankfully, he cared enough to ensure it reached its rightful owner. He carefully repacked it and sent it to the Governor of Madras with a polite letter. From there, it finally made its way to Lambton.

THE PILOT PROJECT IN BANGALORE

While waiting for his equipment to arrive, Lambton—never one to let the grass grow under his feet—decided to carry out an initial survey near Bangalore. A pilot, if you will.

Bangalore was an ideal starting point. It sat near the centre of the peninsula, almost exactly along the central spine of the country. This was the north-south line—the Great Arc—that Lambton planned to triangulate along, measuring it meticulously to take a crack at determining the exact shape of the Earth.

But that was all to come later. First, he needed to set up a trial baseline.

The monsoon rains had drenched the landscape in the first week of October 1800 but the Sun was warm the day Lambton set out to begin work. There were about thirty-five men in the group—Lambton himself, a handful of European surveyors, an interpreter, some guards, and perhaps a carpenter. Most of the party were Indian porters, trudging several kilometers under the weight of all the equipment.

The 100 foot steel chain was the star of the show for setting up a baseline. Besides this all-important item, the porters carried iron stands, wooden boxes, telescopes of various sizes, wooden poles, rods, planks, screws, nails, hammers and an assortment of other tools.

Finally, they arrived at the spot Lambton had carefully chosen. He had already surveyed the area around Bangalore, selecting terrain that was reasonably flat—ideal for establishing a baseline. At the same time, the location needed to offer clear sightlines through the theodolite, whether to hillocks or other easily visible landmarks.

This was also Lambton's opportunity to fine-tune his methods. Since this baseline would form the foundation for countless triangles and complex calculations, it had to be absolutely straight and correctly measured. After all, he had maps of the entire country in mind—he could hardly go about that properly if his baseline was askew.

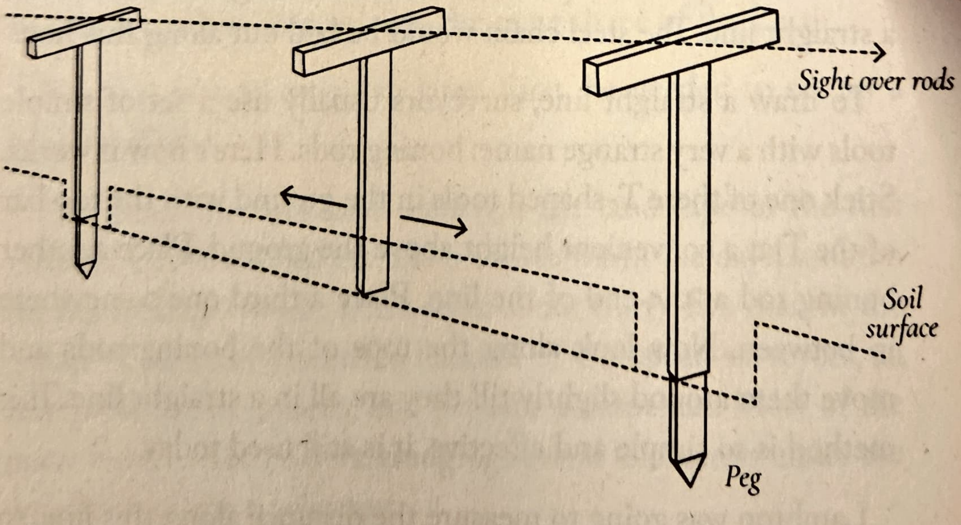
The trial for what was to become one of the largest scientific endeavours of the century began on 14 October 1800, near Banaswadi in Bangalore.

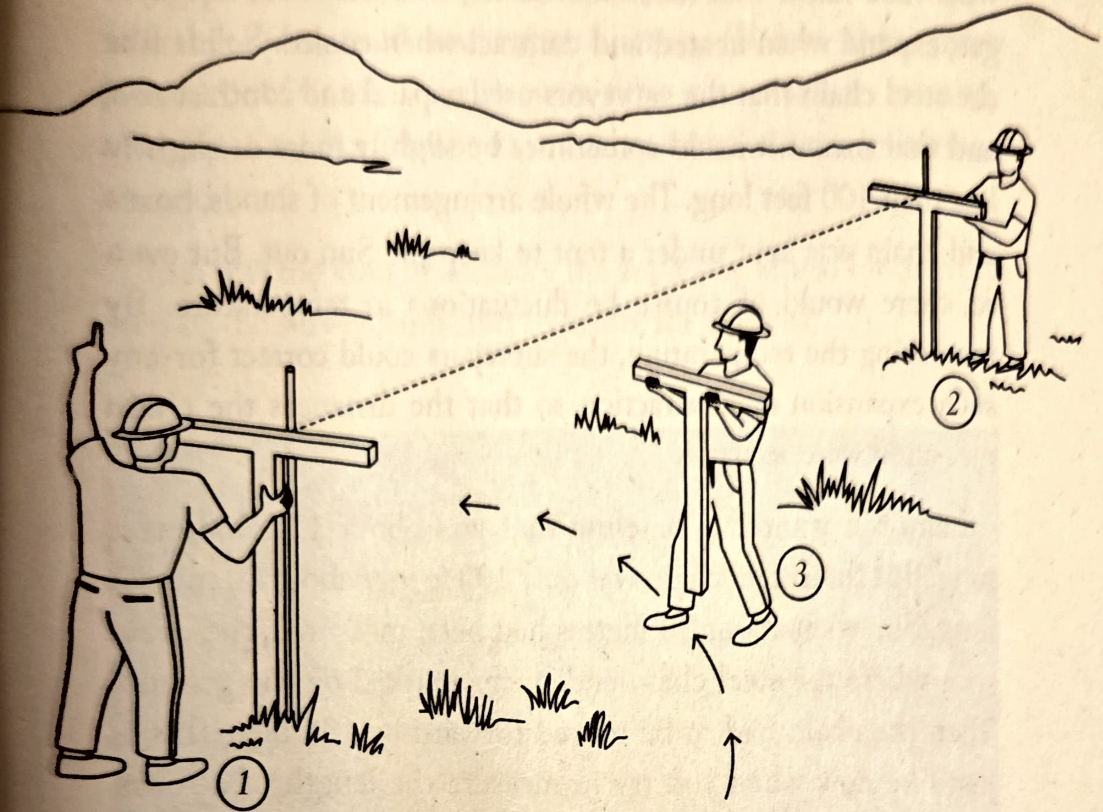
The first step in the operations sounded straightforward: draw a straight line. The steel chain would be laid out along this line.

To draw a straight line, surveyors usually use a set of simple tools with a very strange name: boning rods. Here's how it works. Stick one of these T-shaped tools in the ground with the top bar of the T at a convenient height above the ground. Place another boning rod at the end of the line. Place a third one somewhere in between. Now look along the tops of the boning rods and move them around slightly till they are all in a straight line. This method is so simple and effective, it is still used today.

Lambton was going to measure the distance along this line, so he had to be absolutely certain that it was completely, totally and utterly straight. Naturally, his method was slightly more exacting. He placed a telescope on a tripod at the start point and used that for sighting. He used narrow wooden pieces with long keyhole-like slits in them—these were called vanes—and attached them to the boning rods, then sighted through the telescope so that all the vanes were aligned. There must have been much calling out for small adjustments before everything was lined up to Lambton's satisfaction: 'Move the rod . . . just . . . a little to the left. A little lower. Back up and to the right . . .'

TO SIGHT: In surveying, sighting refers to the act of looking at a distant object, either directly or through a surveying instrument.





Once he was satisfied that he had a truly straight line, the steel chain could be placed along it. But rather than risk damaging the steel chain by keeping it on the ground, the surveyors kept it inside five specially made wooden boxes, each about as long as a bus, all lined up end to end. Specially made iron stands were driven into the ground along the straight line, and the wooden boxes were placed on them. If the iron stands were in a proper straight line, the boxes would align perfectly, and the chain inside them would be absolutely straight too.

The surveyors were such sticklers for accuracy that once the chain was set up, they also kept a thermometer inside each of the five wooden boxes that the chain nestled in. Can you guess why? You know that most substances, whether solid, liquid or gas, expand when heated and contract when cooled. Solids like the steel chain that the surveyors used expand and contract too, and that meant it could sometimes be slightly more or slightly less than 100 feet long. The whole arrangement of stands, boxes and chain was kept under a tent to keep the Sun out. But even so, there would of course be fluctuations in temperature. By measuring the temperature, the surveyors could correct for any such expansion or contraction so that the distances the chain measured were accurate.

Lambton wanted a baseline that was about 12 kilometres long. But their steel chain was only 100 feet or about 30 metres long. So, when about 30 metres had been measured, the exact spot where the steel chain ended was marked on the ground. Then the chain had to be moved forward by 100 feet. This is just like how when you try to measure the length of a room with a small ruler, you have to keep moving it forward after each measurement. But moving this chain was no easy matter. The chain was treated like a baby—with great care. Porters delicately lifted the chain out of the boxes and gingerly laid it on the ground. Others set up the stands in their new positions, set up the wooden boxes on them and then the chain was lifted and kept inside the boxes.

And so they went, proceeding 100 feet or about 30 metres at a time. Some days, that was all the surveyors could manage. Other days, they blitzed through 300, 400, sometimes even 600 feet. In between, they encountered deep trenches, rocky ground, roads and villages. Lambton dealt with all these obstacles, revising his methods slightly to deal with these hurdles.

The length of the GTS's first ever baseline was 7.4 miles or 11.9 kilometres. Its northern end was in Banaswadi in

Bangalore, and southern end was in a small rocky area near Haralur. You could walk that distance in less than three hours. But it took the surveyors fifty-seven days to measure this baseline! For Lambton, accuracy was far more important than time.

This was the kind of accuracy the surveyors aimed for at every step of the survey, from start to finish, for decades.

The British in India were infamously unable (perhaps many were unwilling?) to get their tongues around Indian names. GTS reports, especially the earlier ones, are full of names which sound only vaguely familiar. Can you figure out which places the surveyors were referring to here?

1. Kistnaporum
2. Wooritty
3. Mailcottah
4. Muthra
5. Paughar
6. Coomptee
7. Torreefutteepour
8. Mozuffurpoor

Answers:

1. Krishnarajapuram
2. Orathy
3. Melukote
4. Mathura
5. Pavagada
6. Kumta
7. Tori Fatehpur
8. Muzaffarpur

Do you know of any other such names?

A TRIAL OF TRIANGULATION

Setting up the baseline was only the first part of the pilot. The second part was trigonometry.

Like we've already seen, a trigonometrical survey is based on imaginary triangles. Lambton had a baseline that was one side of a triangle. He now needed places that he could sight through the theodolite, which would form the third points of imaginary triangles with the baseline. Using triangulation, he could then calculate how far these points were from the baseline.

He had a choice of convenient spots to choose from: Bangalore's many rocky outcrops, hillocks and the tall *gopuras* or entrance towers of some of its older temples.

He picked a spot that he called Muntapum. This was one of a handful of small watchtowers built in the sixteenth century on rocky outcrops around the city. The 'Muntapum' that Lambton chose for his first sighting was a watchtower in the northern part of Bengaluru. It was a little less than eight kilometres from the northern end of the baseline. Sighting from the northern and southern ends of the baseline he had just established to the 'Muntapam' tower, and then, as a sort of double-check, also from the tower to the two ends of the baseline, he was able to calculate the distances from the two ends of the baseline to the tower.

To put these places on a map, he also had to determine their latitudes and longitudes. He figured out the latitude and longitude of the tower by using astronomical observations (we've seen how you can use stars to figure this out).

Once he knew the distance between the 'Muntapam' and the northern and southern ends of the baseline, Lambton and his crew could use these known distances to draw more imaginary triangles by sighting to other places. Then, he could calculate the distance to and exact positions of those places. For example, they calculated that Bettahalasur, Savanadurga and Shiṿasandra hills were about 20, 30 and 100 kilometres away respectively, from the 'Muntapam' tower.

Once the baseline had been carefully laid down, the sighting of other places was quick. The surveyors didn't have to move 30 metres at a time like they did when measuring the baseline. They could just sight convenient targets through the theodolite (which admittedly was a bear to lug around).

Over the next year and a half, Lambton ranged the land, triangulating from the initial baseline in Bangalore by sighting from hillock to temple to, sometimes, prominent trees. He extended his survey to Srirangapatna, Sira and other places till he had a web of triangles extending more than 200 kilometres around Bangalore. All important towns, hills and temples were plotted on a map.

With this initial survey, Lambton demonstrated how efficiently he could create an accurate map. The trial baseline in Bangalore, it would appear, had definitely been successful.

Now it was time for the real deal.

THE BEGINNING: A BASELINE IN MADRAS

The date was 10 April 1802. The sun beat down mercilessly, as it often did during summer in Madras. Even in the shade, the temperature had already climbed to 30°C. But the heat and humidity did not seem to bother the men who were scurrying about the Madras Racecourse. At first glance, their hats and trousers might have suggested they were spectators waiting for a horse race. Yet their serious expressions told a different story. Besides, no race would be held this early in the morning.

Major Lambton glanced absently at the empty stands behind him before turning his attention back to the setup in front of him. To a casual observer, it would have looked curious. Very curious. A row of tripods stood in a straight line, each bearing on it a long wooden box. A sturdy steel chain extended from one of them. Lambton bent down, examining a silk thread and the plumb bob hanging from it. He watched with satisfaction as it dangled precisely over a hollow bamboo marker embedded in the ground.

The entire apparatus was sheltered under a tent.

He ran through a checklist in his mind. Tripods aligned—check. Plumb line—check. Thermometers in the coffers—check. Tent securely pitched to block the harsh sunlight—check. Rods, telescopes, poles and other instruments set for sighting—check.

Everything was ready. He nodded. It was time.

Lambton had been preparing for this day for weeks. He had scouted the countryside near Madras for many days, deciding on the best spot to begin his 'mathematical and geographical survey' as he called it. It wouldn't be until 1818—sixteen years later—that this project would officially be named the Great Trigonometrical Survey (GTS), the name we know it by today.

Another crucial instrument was on its way from England, but rather than sit around waiting for it, Lambton had decided to start work on the Madras Baseline. He chose the Madras Racecourse to set up the baseline. Why here particularly? Because it was close to St Thomas Mount, which sat on the 13th parallel, the same latitude as Bangalore. Lambton was already familiar with the Bangalore region, which would be useful when he extended his triangulation from coast to coast, going from Madras to Bangalore and onwards to Mangalore along this latitude. Moreover, Bangalore lay almost perfectly on India's central north-south meridian, the very line he intended to measure.

Even as he planned the Madras Baseline, Lambton was already thinking ahead to the larger triangulation project.

It took Lambton and his team nearly a month and a half to complete the baseline. It began at the Madras Racecourse in Guindy, ran south through Velachery Lake, past 100 Feet Road in Ram Nagar, and stretched all the way to Sholinganallur, just east of a hillock in Perumbakkam. As in his Bangalore trial baseline, the entire 12.2-kilometre length was measured meticulously using a 100-foot long steel chain.

But there was no time for celebration. The work had only just begun.

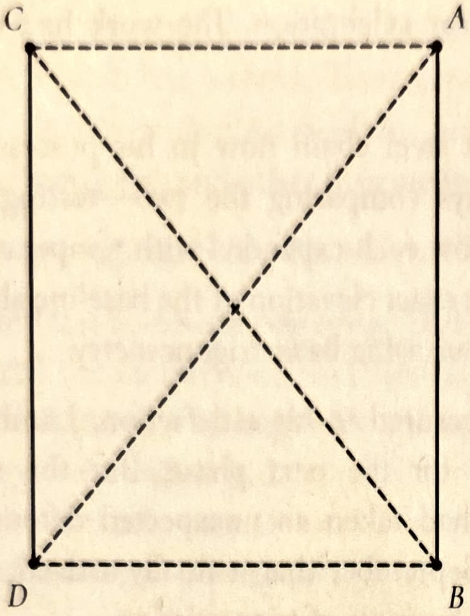
With a second 100-foot steel chain now in his possession, Lambton spent several days comparing the two—testing for differences in length and how each expanded with temperature. Next came determining the exact elevation of the baseline above sea level, a task he carried out using basic trigonometry.

Once everything was measured to his satisfaction, Lambton and his team were ready for the next phase. But the new theodolite from England had taken an unexpected detour to Mauritius. It wasn't until September that it finally arrived, and they could get down to the business of triangulation.

Lambton first climbed St Thomas Mount to observe the angles formed between the hill and the two ends of the baseline. Of course, he wasn't alone—several other surveyors accompanied him, and twenty-four groaning men hauled up the heavy theodolite, while porters carried tents, equipment and other surveying tools. Next, he ascended Perumbakkam Hill and repeated the process. Now, he had four crucial points:

- The north end of the baseline
- The south end of the baseline
- St Thomas Mount
- Perumbakkam Hill

With the measured angles of sight from each point to the others and the precisely measured baseline, he had everything he needed. These four points formed four interconnected triangles, which he could now use to calculate the exact distance between St Thomas Mount and Perumbakkam Hill.



The 4 Triangles:

ABC
ABD
CBD
CAD

A - Northern end of the Baseline
B - Southern end of the Baseline
C - St Thomas Mount
D - Perumbakkam Hill

Since this distance would be the basis for further calculations all the way to Bangalore, Lambton wanted to ensure it was measured with utmost precision. Having four triangles to calculate this distance allowed him to cross-check for errors. For instance, when he calculated the distance between the two hills using two different imaginary triangles—

1. St Thomas Mount—North end of baseline—Perumbakkam Hill
2. Perumbakkam Hill—South end of baseline—St Thomas Mount

—he found that the results differed by just 3 centimetres. Given that the distance between the two hills was 13 kilometres, this was an exceptionally small error.

The last process in the surveying methodology was to observe stars so as to pinpoint the locations of various places.

FROM COAST TO COAST

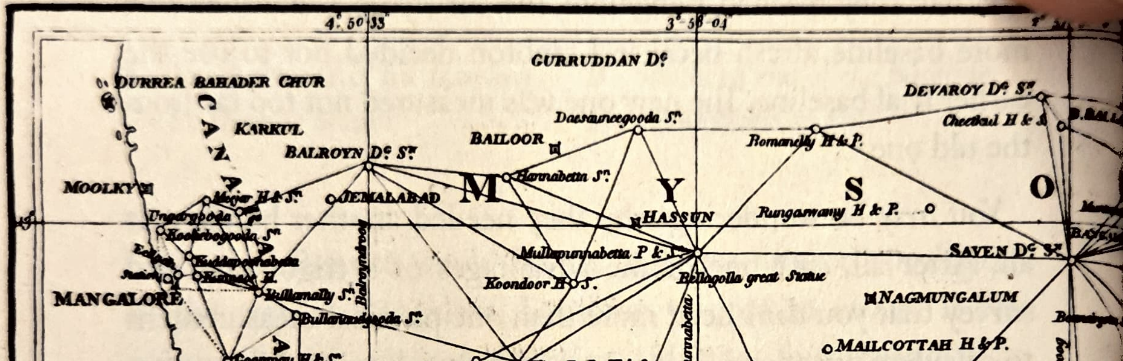
And in this way, the surveyors triangulated and determined the exact positions of a number of places and hills in the area. Gradually, they moved west along the same parallel, 13°N, triangle by imaginary triangle, finding out the positions of places that until then had been drawn on maps but not with any great accuracy.

When they reached Bangalore, the surveyors established one more baseline afresh because Lambton decided not to use the earlier trial baseline. The new one was measured not too far from the old one.

You may be wondering why they needed another baseline at all. After all, isn't one of the advantages of a trigonometrical survey that you *don't* need more than one physical measurement to calculate distances? This is true in theory, but in reality, errors creep into even the most fastidious measurements. And with each measurement based on a calculation, the errors will add up. This is why surveyors usually prefer to have more than one baseline when working over large areas.

The other good thing about measuring a new baseline once you've triangulated your way across some distance—it can show how you're doing in terms of accuracy. For example, the new Bangalore baseline as measured on the ground with the steel chain was 11.57 kilometres. To verify the accuracy of the trigonometrical survey, Lambton and his men also calculated the distance between the two ends of the Bangalore baseline. Remember the baseline you measured between you and your friend at the park? It's like calculating the length of that baseline using the triangle made by, say, the dog, cat and squirrel, and then comparing that number to the measurement taken with a tape measure.

The survey party had been drawing their series of connected imaginary triangles and calculating the distances between different points, all the way from the Madras baseline, 280 kilometres away. Now they 'drew' a triangle with the Bangalore baseline as one of the unknown sides and then calculated its distance.

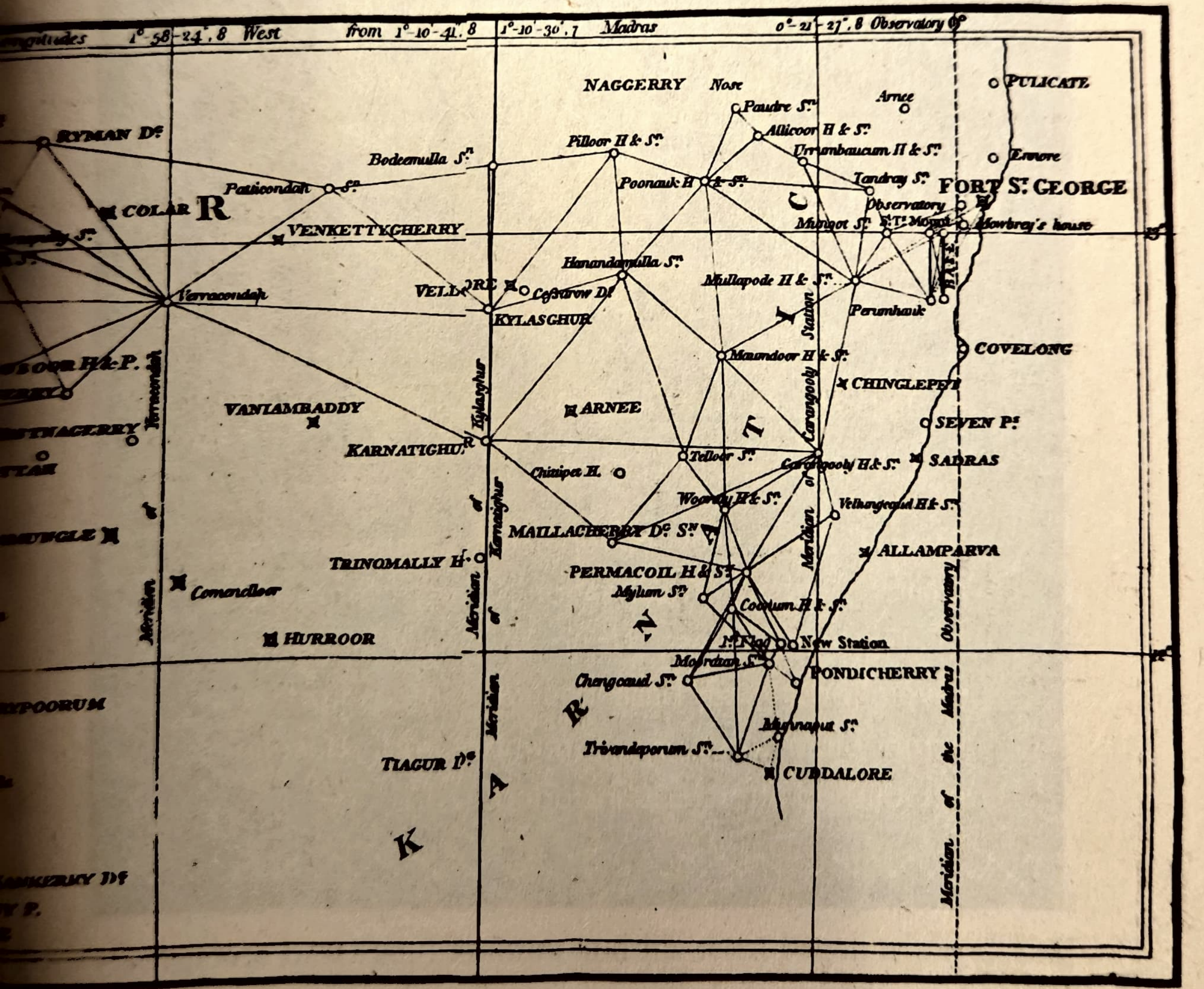


DURREA BAHADER GHUR
KARKUL
BALROYN D° S.
GURRUDDAN D°
Daesauneegooda S.
BAILOOR
DEVAROY D° S.
Chectaul H & S
Romandly H & P.
MOOLKY
JEMALABAD
M Y S O
HASSUN
Rungamany H & P.
SAVEN D° S.
MANGALORE
Koondoor H & S.
Bellagolla great Statue
NAGMUNGALUM
MAILCOTTAH H & P.
Goompay H & S.
Soobrananee H & P.
Koondhully H & S.
KOOMLAH
KASRAGOODA
MARRAKERRA
Bettaipoor H & S.
SERINGAPATAM P.
MALLAVILLY
BAEKUL
MYSOOR
H & S.
WOOS D°
Taddiandamole
Veer Rajenderpet H.
Poodacherrum H.
Mount Delli peak & S.
Meridian
CANNANORE
Station
TELLICHERRY
COIMB
Kumbletarine H.
SATTIMUNGALUM
British Miles.
CANARA
MALABAR

General Plan of the Triangles

The result? The difference between the measurement on the ground using the steel chain and the distance calculated through triangulation was less than 10 centimetres—an astonishingly small error! This relentless focus on accuracy is what made the GTS's maps inch-perfect!

Lambton delivered on his promise to the authorities to produce highly precise maps. For instance, after triangulating up to Mangalore and completing his calculations, he discovered that the actual distance between Madras and Mangalore was a staggering 38 miles (61 kilometres) shorter than previously believed!


1°-58'-24".8 West
from 1°-10'-41".8
1°-10'-30".7
Madras
0°-21'-27".8 Observatory
NAGGERRY
Nose
Paudre St.
Allicoor H & St.
Urrambaucum H & St.
Arnee
PULICATE
Ennore
Pilloor H & St.
Bodeemulla St.
Poonauk H & St.
Tandray St.
FORT St. GEORGE
Observatory
Mungot St.
St. T. Mount
Mowbray's house
Patticondah St.
COLAR
R
VENKETTYGHERRY
Hanandamulla St.
Mullapode H & St.
VELLORE
Cossarow Dr.
KYLASGHUR
Verracondah
Perumbauk
BASE
C
Y
COVELONG
Maundoor H & St.
Carangooly Station
CHINGLEPET
VANIAMBADDY
ARNEE
Kylasghur
Verracondah
KARNATIGHUR
T
SEVEN P.
Telloor St.
Carangooly H & St.
SADRAS
Chittipet H.
Woardy H & St.
Velhangeaud H & St.
MAILLACHERRY Dr. St.
A
ALLAMPARVA
TRINOMALLY H.
Meridian of Karnatighur
PERMACOIL H & St.
Mylum St.
Comendloor
Coolum H & St.
N
HURROOR
Meridian of Verracondah
Meridian of Carangooly Station
Flag
New Station
Moordum St.
PONDICHERRY
Chengcaud St.
R
Mannapur St.
Trivandaporum St.
TIAGUR Dr.
CUDDALORE
A
Meridian of Kylasghur
Meridian of the Madras Observatory
K

After his trial baseline in Bangalore, from which he triangulated to a second trial baseline in Srirangapatna, the GTS team under Lambton went on to measure eleven more baselines. Between 1802 and 1825, they established baselines at:

- Madras
- Bangalore
- Coimbatore
- Thanjavur
- Palayamkottai (Tirunelveli)
- Gooty
- Guntur
- Kumta (near Gokarna, Karnataka)
- Bidar
- Takarkheda (near Amaravati, Maharashtra)
- Sironj (Madhya Pradesh)

After 1830, surveyors replaced Lambton's steel chains with compensation bars, introduced by George Everest. Using this new apparatus, several additional baselines were measured, and some older ones were re-measured. Baselines established after 1830 included:

- Calcutta
- Dehradun
- Sironj
- Bidar
- Sonakhoda (near Ramganj, West Bengal)
- Attock (Pakistan)
- Karachi (Pakistan)
- Vishakapatnam
- Bangalore
- Kanyakumari

Do you live near any of these places where a baseline was measured?

Remember Lambton's 'grand desire'—his ambition to measure the shape of the Earth? To achieve this, he planned a chain of triangles snaking up the central spine of India. This network would allow him to calculate the distance between two latitudes, or, in other words, how much a degree of longitude measured at different points along that spine.

This was the question that Teams Egg and Grapefruit had left unanswered: How much does the Earth curve at the tropics?

To 'draw' that chain of north-south triangles, from the Bangalore baseline, Lambton and his team began triangulating southwards, extending their survey all the way to Kanyakumari.

Once they reached the southern tip of the subcontinent, they returned to Bangalore and continued extending their chain of triangles northward, roughly along the same longitude.

Along the way, several chains of triangles branched off to the east and west. These chains of triangles were called the longitudinal series and included the Bombay Longitudinal, the Calcutta Longitudinal, the Sambalpur Longitudinal, the Kathiawar Longitudinal and others.

LONGITUDINAL SERIES: A confusing term, since these measurements actually follow a latitude. However, they are called 'longitudinal' because they are used to determine degrees of longitude as the survey moves along a latitude.

Lambton was on his way from Hyderabad to Nagpur when he passed away in 1823 at Hinganghat, near Wardha in Maharashtra. It was up to his successor, Colonel George Everest, to complete what became known as the Great Arc of the Meridian.

FORMIDABLE AND FIERY

Sir George Everest—even if you haven't heard of him, there is no doubt you know his last name.

It's ironic that his name has been immortalised by Mount Everest. There is no evidence whatsoever that the man had even seen the mountain. When his assistant Andrew Waugh suggested naming the mountain after him, Everest wasn't even in favour of it. For one thing, he always favoured using local names wherever possible. Besides, he didn't think his name could be written and pronounced correctly in Indian languages. Well, leave alone other languages, it turned out that even English speakers didn't get his name right. Everest was particular that his name be pronounced Eve-rist, but as we all know, the mountain is now known as Ever-rest.

He may have had nothing to do with the mountain, but George Everest was a stalwart surveyor and a worthy successor to Lambton. He maintained the strict standards by which Lambton conducted the survey. He even improved upon it, introducing new instruments and techniques to make the survey more efficient. Along with all this, he brought in his own exacting requirements that drove his team quite wild trying to follow them.

He had immense respect for Lambton, but where Lambton was genial, easygoing, and by all accounts a kind, humble person, Everest was demanding, curt, and quick to take offence.

When a fellow officer called him a *Kumpass Wala*, 'compass-bearer', the colloquial term for surveyors of the time, Everest wasn't pleased. 'I'm not a Kumpass Wala, but Surveyor General and Superintendent of the Great Trigonometrical Survey of India,' he retorted sharply. Everest didn't rest until he received apologies from the officer. He also made it a rule that he would henceforth be known as Surveyor General Sahib Bahadur in all official correspondence. One couldn't say he wasn't deserving of it, of course!

George Everest was born in England on 4 July 1790 While his exact birthplace remains unknown, he was baptised in Greenwich—yes, by a delightful coincidence, the same Greenwich of the Prime Meridian—so he was likely born theareabouts. At just fourteen, he chose a military career and received his education at the Royal Military College in England.

As a boy of sixteen, Everest arrived in India to join the East India Company's army. His expertise in mathematics and astronomy quickly set him apart, and he excelled in the surveying projects he was assigned to. His talents caught the attention of William Lambton, who, in his later years, was searching for someone with the 'zeal, constitution, and attainments' to carry forward the work of the Great Trigonometrical Survey, and his legacy. Seeing these qualities in Everest, Lambton appointed him as his chief assistant in 1818—a decision that would prove to be a wise one.

Everest succeeded Lambton as superintendent of the GTS when Lambton died in 1823. He became Surveyor General of India in 1830.

For much of his career, Everest had to contend with shortages of funds and staff, and a lack of support from the EIC headquarters in London. He endured very hard conditions in the field and his own poor health tripped him up ever so often, leaving him frail and paralyzed at one point. Despite all these hurdles, he completed the measurement of the Great Meridional Arc. He retired in 1843 and died in 1866.

BEGINNER'S BAD LUCK

Everest's journey with the GTS did not begin well.

Lambton worked briefly with Everest to assess his abilities before assigning him his first task: surveying the Krishna-Godavari region near Hyderabad. On paper, it seemed a straightforward assignment. Lambton had already measured baselines at Bidar, Gooty and Guntur. All Everest and his team had to do was map out some triangles.

But that was easier said than done.

The conditions in the field were hard. The area was covered in dense jungle, home to wild beasts. In fact, a few months earlier, a tiger had killed one member of the team. It was the height of the monsoon, and the team trudged through the thick, wet jungles, full of predators and insects and jungle fever.

Apart from his usual survey team—which you will read more about in the next few chapters—Everest's retinue included elephants and mahouts to manage them. Why elephants? Because they were essential for navigating deep into the jungle and clearing large tracts of land.

As you may recall, there could be no obstructions between one observation point and another—after all, how could a target be sighted if it wasn't visible? Lambton had often used temple towers and hilltops as stations to observe distant points. However, in the dense forests where Everest was now working, no such vantage points were available. Instead, his team had to create their own.

To do this, they built tall observation towers to serve as trigonometrical stations. Even then, they needed clear sight lines, which meant cutting down trees over 100 feet tall to establish these lines of sight.

LINE OF SIGHT (or sight line) refers to the imaginary straight line between an observer's eye and the object being viewed, unobstructed by any obstacles.

It was gruelling, complex work, but the team was exceptional—well-trained under Lambton's guidance. Even Everest, known for his gruff demeanour, set aside his usual grumpiness to express admiration for them. He strongly objected to his men being referred to as 'coolies', a derogatory term for unskilled labourers, and insisted they be called *khalasis* or *lascars*—a recognition of their skill and expertise.

Everest and his team of khalasis pushed forward, battling the unforgiving jungle. But nature proved too formidable. The entire team was struck down by jungle fever—a severe form of malaria. Weak and unable to walk, they had to be physically carried out of the jungle by villagers from nearby settlements. Tragically, fifteen of the 150 men lost their lives. Everest survived, but only just. The fever would haunt him for years to come.

The very next year, another severe bout of illness forced Everest to take a year-long sick leave. Though he recovered, his health never fully stabilised, and the lingering effects of the fever stayed with him for the rest of his life.

EXTENDING THE GREAT ARC

In 1822, Everest, somewhat recovered, returned to India. He was tasked with building a new east-to-west arc that would fix the position of Bombay. There were no jungles, no fevers and no wild beasts on this route—and this was when Everest became free to innovate and bring into effect new ways of surveying that changed the way the GTS worked.

It was soon after this that Lambton passed away and Everest took over his role as head of the Survey. The initial adjustment period was a difficult one for everybody. The team was already weighed down by the difficulties of surveying both in the field and out of it. In place of Lambton's geniality, they now had to adjust to Everest and his ways. It didn't help that Everest's attitude towards them wasn't always kindly.

Eventually, they found that Everest's bark was worse than his bite. It became clear that what mattered most to him was the Survey, and he would go to great lengths for it to succeed. And he expected the same from others. An understanding was reached, and the Survey progressed.

Now it was time to extend the Great Arc (the imaginary line they were drawing across the surface of the Earth to measure its curvature) northwards. But once again, Everest was struck down by illness. Aching bones, shivers, difficulty sleeping—any other person would have fled. But Everest hung on. His limbs paralysed, he had to be carried around in a palanquin. The jostling and bumping was excruciatingly painful, but he bore it. He was too weak to stand and needed his team to physically support him to operate the theodolite or zenith sector, but operate it he did. Doctors advised him to take time off to rest and recuperate. But Everest knew this juncture was crucial. If he left now, the Arc could stall, and he couldn't have that happening. He forged on.

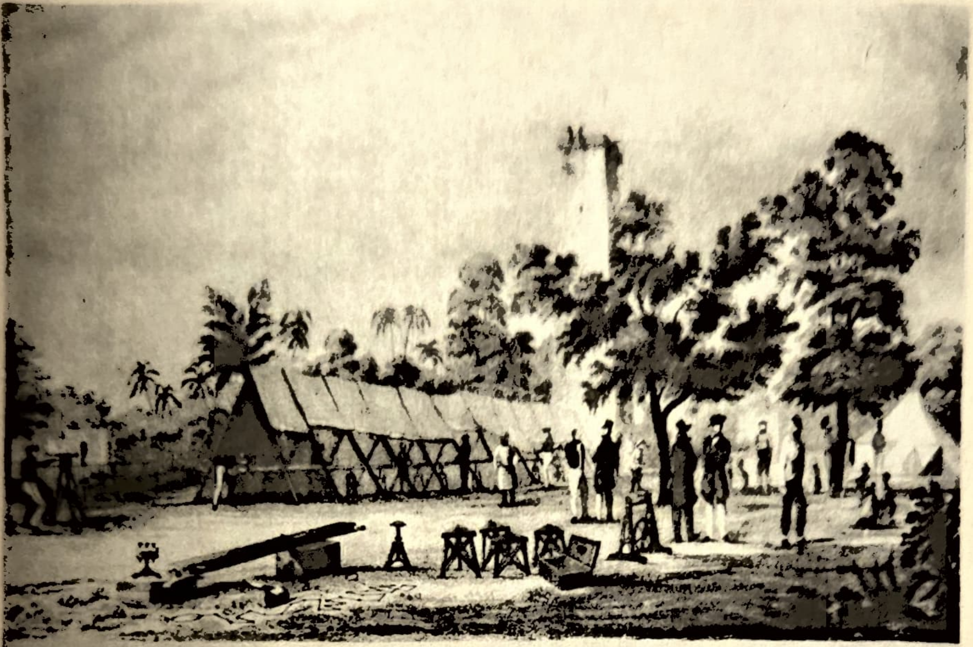
Finally, in 1824, the Arc crossed the Narmada River. The Great Arc now stretched from Kanyakumari where Lambton had started it, all the way up to Kalyanpur in Madhya Pradesh, a distance of about 1,600 kilometres.

It was to grow even longer.

Once Everest knew the Arc was rolling forward steadily, he finally agreed to go to England for five years to recover. But it was hardly a vacation—he remained as active as ever, writing reports, acquiring new instruments, making plans, and even securing the prestigious position of Surveyor General of India. He used this promotion to promote the Great Arc even more and acquire more funding.

During his time away from India, the GTS team surveyed east towards Calcutta, then the capital of British India, making a chain of triangles that led from the Arc to Calcutta. This was the Calcutta Longitudinal.

After Everest came back, he supervised the completion of the Calcutta Longitudinal, and he invited officials of the EIC to observe the activity of the GTS. This was the first time many of these higher-ups got the opportunity to actually see what this great big mysterious operation that swallowed so much of the EIC's funds was all about!



CALCUTTA BASE LINE

from a sketch by James Prinsep, Jany. 1832
[III. 495 ; IV. ch. iv].

Printed at the Survey of India Offices [illegible]

After completing the Calcutta Longitudinal, Everest turned his attention to extending the Great Arc northwards. At this stage, he deviated from Lambton's approach of covering the entire landscape with a web of interconnected triangles. Instead, he introduced a 'gridiron' system—a network of horizontal and vertical arcs forming a grid. The areas between these arcs would then be mapped using less expensive, conventional surveying methods. This significantly sped up the Survey's progress.

To further increase efficiency, Everest deployed multiple teams to work simultaneously on different arcs. While this drove up costs, it dramatically improved the speed and scale of the operation.

With this shift, Everest transformed the Great Trigonometrical Survey from Lambton's underfunded, close-knit team into a super efficient, extremely focused enterprise—a well-oiled machine.

In spite of all the planning, the surveyors frequently stumbled upon unexpected challenges. They managed to come up with clever workarounds.

For instance, the delta along the Ganga River was both densely populated and extremely flat, presenting two major obstacles in surveying towards Calcutta. First, a constant haze from millions of household cooking fires obscured visibility. This issue was resolved using Everest's luminous signals, which you'll read about in the next chapter.

The second challenge was the lack of natural high points, such as hills or mountains, to establish sight lines. The team initially attempted to construct towers using bamboo poles, but these swayed dangerously in the wind, jeopardising both the theodolite and the surveyors themselves. Everest found a clever workaround—he repurposed existing towers that had once been part of a visual messaging system, where signallers flashed short telegraphic messages from one tower to another. You'll read about some of them later in the book. However, such old towers were not always conveniently available everywhere the GTS needed them, so very often, Everest had new towers built specifically for sighting.

A similar problem arose while surveying the plains near Delhi. This time, Everest took a proactive approach—he spent two years and thousands of pounds constructing towers at predetermined locations before the survey even began. Only once these structures were in place did the actual measurements commence. Remarkably, some of these towers still stand today.

In some cases, the surveyors simply got lucky. Historic structures such as the buildings of Fatehpur Sikri and the dome of Akbar's tomb in Sikandra provided ready-made vantage points, saving both time and effort.

EVEREST'S INNOVATIONS

Everest was a master innovator. He made sweeping changes in the way the GTS worked, making it quicker and more efficient.

LIGHT SIGNALS

During a survey, to look at a point that is at a great distance, you need to mark it in some way. Cloth flags, flagpoles, stone cairns, wooden poles, bundles of brushwood, and other such objects were commonly used as signals in the Survey. But the problem with these signals was that it was difficult for the surveyor to sight them beyond a distance of about ten miles. Haze and dust made things blurry. Many times, they couldn't distinguish the signal from the surroundings.

So, they had to wait for the rainy season when the dust settled and the air cleared. But the rainy season came with its own problems, of course.

The alternative was to use some form of light signals. Flares (a temporary flash of light/flame), and occasionally, bonfires were used during Lambton's time. But flares burnt out too soon and were unpredictable. Bonfires were too large and diffuse. For accuracy, they just wouldn't do.

One of Everest's greatest contributions was to improve the way signals were used in the Survey.

During the day, Everest used heliotropes. These are instruments that use mirrors to reflect flashes of sunlight to fixed positions in the distance. It's like when you catch sunlight on a shiny object and reflect it on a wall or floor for kids or kittens to chase. The signals could be sent up to a distance of 160 kilometres!

For surveying during the night, Everest introduced a simple terracotta lamp. The bulb was a large cup filled with cotton seeds and oil—essentially, a large *deepa* or *diya*. Over this, he placed a large clay pot with a slit on one side through which light could shine. The light was contained in one spot and could be seen from up to 65 kilometres away. These lamps worked in all conditions except when it was windy. Clay pots and dishes were cheap and readily available everywhere, even simple enough to make, if required.

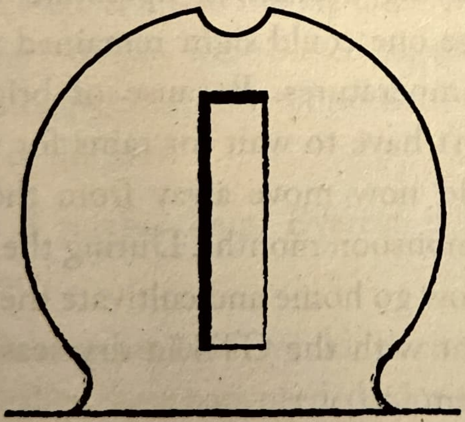


Diagram of an overturned pot with a slit

Blue lights or luminous lights and flares changed nighttime surveying. One variation called the 'blue light' was the brightest flare available. Everest had his own recipe for the mixture for this flare, involving 739 parts! It included 'sulphur 136 parts; nitre 544; arsenic 32; indigo 20' and so on. All this was wrapped in cloth and packed into a sheep's bladder. Each flare had to weigh around 1.3 kilograms. Substituting ingredients or tinkering with quantities was a recipe for disaster: the flare would not light up. Worse, it might explode. Maybe that would've been fun as fireworks, but not as signals! These flares could burn for only up to six minutes at a time.

With the terracotta lamps and the blue flares, surveyors could now survey at night, which turned out to be a brilliant development. Nighttime surveying had lots of advantages.

The surveyors could see these signals 80 kilometres away. It saved many wasted days waiting for haze and dust to clear. Refraction due to the Earth's atmosphere (which you'll read about in the next few chapters) made it possible to see even farther during nighttime than during daytime, so night signals helped with that. Temperature affects how far you can see. Nighttime surveying avoided temperature fluctuations, and the total distance one could sight remained roughly constant at nighttime temperatures. Because of brighter lights, the survey now didn't have to wait for rains for the dust to clear. The survey could now move away from the hazardous and uncomfortable monsoon months. During the rainy season, the workers could now go home and cultivate their fields and then seek employment with the GTS in dry seasons. This was an advantage to them too.

A NEW THEODOLITE: Everest introduced a specially designed 90-centimetre theodolite to replace the Great Theodolite which had suffered breaks and repairs. Finally, heavy winds had once hit the survey camp and blown it over, and it was heavily damaged.

COMPENSATION BARS TO REPLACE STEEL CHAINS

The 100-foot chain had become worn with use. Besides, temperature variations affected the length of the chain. So, in order to improve the accuracy of the baselines as the Arc spread out over India, Everest introduced compensation bars, an instrument that had been recently designed in England. These were made of twin bars: one iron and one brass. When ambient temperature increased, the two metals underwent expansion at different rates. The two bars were bolted together in such a way that variations in temperature did not result in any change in the measured length of the bars.

Each bar was 3 metres long. Everest bought six sets of compensation bars.

You might think metal bars would be rugged and sturdy instruments. In reality, these bars needed a lot of tender care and had some very specific needs. To prevent the bars from rusting, they had to be constantly treated with either animal fat or a concoction of mercury mixed with fat or wax. (Wonder what health effects that had on those who were handling the bars!) The microscopes attached to the bars had to be cleaned with goose fat and silk. To keep the box in which the bars were stored free of insects, Everest recommended using neem leaves. And like their predecessors, the steel chains, these metal bars also needed tents to protect them from the sun.

SYED MIR MOHSIN: JEWELLER, INSTRUMENTATION ENGINEER, INVENTOR

• • •

Everest's many innovations powered the GTS through some difficult situations. As someone who approached problem-solving in original and imaginative ways, he prized talent and creativity when he saw it. Syed Mir Mohsin was one such person, an unsung inventor who worked with Everest and won his trust.

It was an ordinary morning in 1819 when **Seid Mir Mohsin Husain's** life changed course. As usual, Seid Mohsin (sometimes also spelt Syed Mohsin) was working in a room at the back of George Gordon's jewellery shop in Madras. Perhaps Mohsin sometimes missed his village near Arcot where he was born. But even with his family's ties to the Nawab of Arcot, there was no work for him back there. Here in Madras, Mohsin enjoyed working on fine silver jewellery and other items that old Mr Gordon's shop was known for.

Mohsin heard the front doors swing open, followed by the quick exchange of voices between the visitors and Mr Gordon. Englishmen, he thought absently. He understood very little of their language, and besides, he was focused on the silver chain he was crafting.

Then, to his surprise, Mr Gordon called him over.

The Europeans were military officers. One of their instruments had broken down, and their work had ground to a halt. The officers had no time and no budget to send the apparatus back to England to be fixed. Jewellers were used to working on delicate pieces. Could Mohsin possibly fix it?

Mohsin had never really looked at such an instrument. That did not stop him from examining it, mulling over it and then repairing it. Lt Col Valentine Blacker, who had brought in the equipment, was thoroughly impressed with Mohsin's 'uncommon intelligence and acuteness'. From then on, he frequently turned to the jewellery maker for help with his military gear. Four years later, in 1823, when Blacker became Surveyor General of India and moved to Calcutta, he took Mohsin Husain with him. Soon the former jeweller was appointed instrument maker at the Surveyor General's office.

In 1830, when George Everest became Surveyor General of India, Mohsin found himself busier than ever. As an instrument maker, he set up a field workshop to ensure that surveyors' equipment could be repaired on-site.

Everest, known for his often waspish temperament, had nothing but praise for Mohsin. He declared that he could entrust him with even the most intricate instruments, confident that Mohsin could dismantle and reassemble them flawlessly. He admired Mohsin's 'inventive talent', calling him a man of 'genius and originality'.

Everest had also brought over an instrument maker from England, named Henry Barrow. Designated as the Mathematical Instrument Maker, Barrow worked in Calcutta. His job was to design, manufacture and repair theodolites, compensation bars, retracting measuring tapes, chronometers, barometers, microscopes, telescopes and many other instruments that the surveyors needed.

Things ran like clockwork. For a while.

In 1839, Everest asked Barrow to fix an altazimuth, also called an astronomical circle. Like theodolites, these were used to measure vertical and horizontal angles. Everest had ordered two of them to replace the zenith sector. But to be functional, both required multiple replacements and new components. Among other things, a new cast iron circle had to be crafted and accurately graduated—meaning it needed to be marked with accurate measurements, much like the millimetre markings on a ruler—to ensure precise readings.

Barrow initially took on this challenging task but later refused, claiming it was too difficult. Naturally, Everest fired him.

Mohsin stepped in. Working closely with Everest, he replaced several components, crafted two new cast iron circles, and meticulously added accurate graduations. He even introduced small but ingenious modifications that made the instrument easier to use.

A delighted Everest documented the entire process in a detailed article for a scientific journal. He also appointed Mohsin as Mathematical Instrument Maker, replacing Barrow and making him the first Indian to hold the position.

Incidentally, Mohsin's inventive brilliance extended beyond surveying. The jeweller from Arcot played a crucial yet largely unacknowledged role in forestry—he was the co-inventor of the Brandis hypsometer, an instrument that foresters worldwide have used for measuring tree heights.

SUBLIME DESIDERATUM

Back to Lambton's original desire: to figure out how curved the surface of the Earth is at the tropics. Everest and his team now had a precisely measured arc, a longitude that spanned 11 degrees of latitude.

Everest and his assistant, Andrew Waugh, conducted 3,000 astronomical observations over countless nights to determine the precise latitudes of three key locations along the Great Arc: one in the north near Dehradun in Uttarakhand, one in the middle near Sironj, Madhya Pradesh, and one in the south at Bidar, Karnataka.

They already had the lengths of these sections meticulously measured on the ground through triangulation. So now, they could compute the length of a degree of latitude. In other words, they could find out how curved the surface of the Earth is at the tropics.

There were reams and reams of laborious calculations. As Everest himself once remarked, geodesists needed to have 'a suitable degree of patience' for such 'tedious computation'.

Finally, it was done. Everest came up with a figure for the ellipticity of the Earth, the degree to which the Earth deviates from being a perfect sphere. This figure came to be known as the Everest Spheroid.

It was a landmark achievement in the history of science. It became the basis of countless studies and calculations across the world.

Lambton was no more, but his *grand desire* was fulfilled.

COMPUTATIONAL CHALLENGES

The mathematical aspect of the Great Trigonometrical Survey (GTS) was enormous! Entire books were filled with data and calculations. The numbers they worked with ranged from 20,888,153.2 (the Earth's radius in feet, as estimated at the time) to 0.00663784607 (the square of the Earth's eccentricity—a measure of how much its shape deviates from a perfect sphere).

The equations and formulae were long, complicated, and numerous—hundreds of them had to be solved. And this was long before computers, ChatGPT or even calculators existed! Instead, surveyors relied on a slide rule, a hand-operated calculating tool that required skill to use.

Mathematicians also used logarithms to simplify calculations, but since they were striving for inch-perfect maps, they used seven figure logarithm tables, ensuring the highest possible accuracy.

Formula No. 1 $N = L(sec^2\theta);\ \frac{N}{M} = a^2;\ y^2 = sin^2\theta;\ \alpha = 1;\ \beta = \frac{1}{2};\ \gamma = \frac{1}{3};\ \delta = \frac{1}{4};\ \varepsilon = \frac{1}{5}$ &c.

" **No. 2** $N = L(sec^2\theta);\ \frac{N}{M} = a^2;\ y^2 = tan^2\theta;\ \alpha = 1;\ \beta = -\frac{1}{2};\ \gamma = \frac{1}{3};\ \delta = -\frac{1}{4};\ \varepsilon = \frac{1}{5}$ &c.

" **No. 3** $N = L(cosec\,\theta);\ \frac{2N}{M} = a^2;\ y = cot\theta;\ \alpha = 1;\ \beta = -\frac{1}{2};\ \gamma = \frac{1}{3};\ \delta = -\frac{1}{4};\ \varepsilon = \frac{1}{5}$ &c.

" **No. 4** $N = [L(tan2\theta) - L(2.sin\theta)];\ \frac{2N}{3M} = a^2;\ y = sin\theta;\ \alpha = 1;\ \beta = \frac{7}{6};\ \gamma = \frac{5}{3};\ \delta = \frac{31}{12};\ \varepsilon = \frac{21}{5}$ &c

By applying which we obtain a new set of equations of the following form:

$$\left.\begin{array}{ll}
\textbf{Formula No. 5} & L(sin^2\theta) = L\left(\frac{N}{M}\right) - \frac{1}{2}N + \frac{1}{24}\cdot\frac{N^2}{M} - \frac{1}{2880}\cdot\frac{N^4}{M^3}\ \&\text{c.} \\
\text{"}\quad \textbf{No. 6} & L(tan^2\theta) = L\left(\frac{N}{M}\right) + \frac{1}{2}N + \frac{1}{24}\cdot\frac{N^2}{M} - \frac{1}{2880}\cdot\frac{N^4}{M^3}\ \&\text{c.} \\
\text{"}\quad \textbf{No. 7} & L(cot\,\theta) = \frac{1}{2}\cdot L\left(\frac{2N}{3M}\right) + \frac{1}{2}N + \frac{1}{12}\cdot\frac{N^2}{M} - \frac{1}{360}\cdot\frac{N^4}{M^3}\ \&\text{c.} \\
\text{"}\quad \textbf{No. 8} & L(sin\,\theta) = \frac{1}{2}\cdot L\left(\frac{2N}{3M}\right) - \frac{7}{18}N + \frac{1}{12}\cdot\frac{N^2}{M} - \frac{2^3}{3^7}\cdot\frac{N^3}{M^2} - \frac{\overline{89}}{2^3\cdot 5\cdot 3^8}\cdot\frac{N^4}{M^3}\ \&\text{c.}
\end{array}\right]\cdots\cdots(y)$$

Here is a small sample taken from a report by Everest about a measurement along the Arc.

THE FORGOTTEN MEN BEHIND THE GTS

Imagine it's the 1830s. You walk into a wilderness in Madhya Pradesh one morning and unexpectedly stumble upon a surveying party. What would you see?

You'd probably hear them before you saw them. Voices in Kannada, Tamil, Hindi, Telugu, Dakhni, or English might drift through the trees—surveyors and workers calling out instructions, people exchanging news or simply chatting. You'd hear the steady thwack of axes as wood was cut—perhaps for cooking fires, boiling water or making surveying poles. You might smell food being cooked over an open flame. You might even hear the laughter of children, for surveying parties often included families.

When William Lambton first began his 'geographical and mathematical survey', his team was small: two messengers, two water-carriers, eight soldiers, an interpreter, a carpenter, a blacksmith and about twenty porters. But within a few years, these parties had grown into huge, mobile communities—closer to a hundred people, often more.

Apart from the surveyors, their assistants and instrument makers, a typical survey party included:

- *Hurkaras* (or *dauriyas*): messengers to relay information, orders, requests or other messages to elsewhere in the country.
- Equipment carriers: forty or fifty men to haul bulky instruments like the theodolite, zenith sector, steel chains, besides tents and other supplies.
- Guards: at least thirty soldiers or armed men, since robbery wasn't uncommon.
- Interpreters and scribes: vital for communication and documentation.
- Blacksmiths, carpenters and other craftsmen: to keep the instruments in good repair
- Cooks and service staff: ensuring the party was well-fed and looked after.

One of the most crucial and daring roles belonged to the flagmen or khalasis. These men ventured deep into tiger-filled jungles, across rivers and up treacherous hills to set up flags and signal lamps—markers for distant sighting. Although it sounds simple, it was anything but that.

Imagine being sent off in a tiny group of three or four, trekking up an unfamiliar hill, only to realise the next peak was actually higher, forcing you to start all over again. Some khalasis were stationed alone on distant hilltops for days or even weeks, tending to a single flag or lamp, their only companions the stars and the occasional roar of a wild animal.

These lamps had to be placed in exactly the right position, say along a particular meridian. Sometimes they had to be kept burning all night, which meant fighting sleep and no mistakes allowed! As Everest once warned, 'The slightest error in the position of the lamp vitiates the whole work.'

Khalasis were also tasked with other specialised jobs such as setting up the instruments in position or working with the tripods.

Surveying parties varied in size, but when Everest moved north from Sironj, he had a small army with him:

- 700 khalasis and camp workers
- Three elephants
- Thirty-four camels to haul equipment

A surveying camp was no small operation—it was a roving city, carving its way through the subcontinent, one measurement at a time.

Many khalasis joined the GTS when Lambton first began his surveying in southern India. Many were accompanied by their families. They continued to work with Lambton as he moved across the peninsula and then northwards. After he died, some of them stayed on to work with Everest, too.

Unfortunately, even though khalasis were highly valued members of the survey party, we do not know much about them at all, not even their names, barring just a few. For instance, we know that Everest recommended pensions for a couple of experienced flagmen named Mutial (Muthyal perhaps) from Chittoor in Andhra Pradesh and Muruga from Ramanathapuram. Both had joined the GTS in the early 1800s under Lambton and had stayed in the job for more than three decades. But we don't know anything more of the lives and stories of these thousands of men who were the backbone of the Survey.

MEASURING A MOUNTAIN

Can you imagine a time when no one knew which the highest mountain in the world was? Practically everyone today knows, duh, it's Mount Everest, of course. But not so when surveyors like Lambton and Everest were traipsing around India, peering into telescopes, figuring out distances and making maps. At that time, many people thought the highest mountain in the world was somewhere in the Andes.

In the 1840s, Everest had finished work on the Great Arc and had retired. The next big target for the GTS was the region between the Great Arc and the most important city in British India at the time, Calcutta. The Calcutta Longitudinal was already in place. Extending straight up from this line were several shorter chains that ran up to the foothills of the Himalayas. Over the next few years, Andrew Waugh, who took over as the Surveyor General after Everest, started work on the Northeast Longitudinal, a series of triangles that ran from Dehradun to Guwahati. On the GTS map on page 5, this is the line of triangles right along the India-Nepal border.

Andrew Scott Waugh (1810–1878) was a British army officer and the Surveyor General of India. He succeeded George Everest in 1843. He led the team that measured the height of Mount Everest and announced that it was the highest mountain in the world. He named the mountain in honour of Everest.

The Northeast Longitudinal hugged the lower reaches of the Himalayas. This gave the surveyors the chance to measure the heights of some of the snowy mountains nearby. On the GTS map, you can see this in the lines that stick out like porcupine quills. In Kumaon, they sighted Nanda Devi and calculated its height at 25,643 feet (7,816 m). This immediately knocked the Andes peaks off the list of contenders for highest mountain in the world. Nanda Devi was in turn knocked off by Kanchenjunga, which was found to be 28,169 feet (8,586 m) high. For a while it seemed this might be the world's highest mountain. Except that there was another peak hiding behind many other summits, which seemed like it might be higher even than Kanchenjunga.

Waugh first referred to this peak as Gamma, later renaming it Peak XV. And he had a strong suspicion that it was the highest mountain in the world. The surveyors couldn't get closer to the mountain because getting permission from either Nepal or Tibet to survey on those lands was impossible. This meant they had to make their theodolite observations of these high Himalayan peaks from more than 150 kilometres away.

This was no easy job. Snowy winds obscure the mountains for most months of the year. At other times of the year, they peep out from behind clouds and snowy drifts for only a few hours during the day. And what's more, since they are all covered with snow, they all look more or less alike, and you had to be very careful about which peak you were observing! One piece of advice given to the surveyors was to make a quick sketch of the peaks right away so that they could record the right ones.

Even with all these hurdles, surveyors managed to get six observations of Peak XV from different places in Bihar near Darbhanga. And they all gave different results for the height! How was one to determine the correct height?

There were further complications. When taking sightings from so far away, atmospheric refraction had to be factored in. There were also discussions about from which point exactly the mountain's height was to be calculated, or in other words, where the elevation zero was.

This is where Radhanath Sikdar, the Chief Computer, stepped in. Drawing on his exceptional mathematical acumen, he meticulously analysed the raw data to determine the peak's height. It took him and his team two full years before he was satisfied with his result: Peak XV stood at 29,002 feet (8,839.8 metres). (Today, Mount Everest's officially recognised height is 8,848 metres, but this was the best calculation at the time.) Sikdar presented his findings to Waugh, who being just as fastidious about accuracy, had another team verify the calculations. As expected, everything was flawless. Finally, on 1 March 1856, Waugh officially announced that Peak XV—now named Mount Everest—was the highest mountain in the world.

TALLER MOUNTAINS AND SHINY IMAGES

• • •

Take a glass of water and dip a spoon or a pencil into it. Notice how it looks slightly bent? That happens because of refraction—the bending of light as it moves between different materials; in this case, air and water.

Something similar happens in the atmosphere. Light bends as it travels through air of varying densities, making objects—like mountains on the horizon—appear taller than they really are. The more atmosphere the light has to pass through, the stronger the effect.

Temperature and humidity also play a role in refraction. Ever seen shimmering, puddle-like images on a hot road, only to have them vanish as you get closer? That's refraction at work too!

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Radhanath wildly exceeded these modest expectations. He learnt English, but also Greek, Latin and Sanskrit. He was deeply interested in history, literature, mathematics and physics and excelled in all of them.

The teachers from those early days greatly influenced Radhanath. Henry Louis Vivian Derozio was a radical and

RADHANATH SIKDAR: THE HUMAN COMPUTER

The most famous photograph of Radhanath Sikdar, or Sickdhar as he spelt it, shows him wearing a hat a bit like the ones Gandhi and Nehru wore many, many years later. He seems relaxed, but there is a determined set to his mouth, and his large eyes stare directly and intently at the camera. It is an arresting expression, and you wonder if there is anything of the tortured genius about him.

Radhanath Sikdar was born on 5 Oct 1813 in Calcutta. When he was eleven years old, his father sent him and his younger brother to Hindu College (later called Presidency College and now the Presidency University) in Calcutta. He hoped the boys would learn a little English, maybe a smattering of other subjects, enough for them to get jobs, perhaps as clerks.

Radhanath wildly exceeded these modest expectations. He learnt English, but also Greek, Latin and Sanskrit. He was deeply interested in history, literature, mathematics and physics and excelled in all of them.

Two teachers from these early days greatly influenced Radhanath. Henry Louis Vivian Derozio was a radical thinker and the first Indian to write poetry in English. Derozio taught English and history. He also encouraged critical thinking and instilled 'a spirit of inquiry after truth', as Radhanath put it. Radhanath also learnt to stand firmly for what he thought was right. He adamantly refused to marry an eight-year-old child that his family chose for him, even though child marriage was quite common in those days. Another time, he spoke out against the exploitation of some of the Indian employees of the Survey by a European magistrate and refused to back down, even when he was fined a hefty amount.

Radhanath's mathematics teacher was a Scottish physician, John Tytler. It was Tytler who recommended Radhanath's name to Everest who was looking for young men who knew trigonometry. So in December 1831, even before he sat for his final exam, eighteen-year-old Radhanath joined the GTS. He was hired as a computer, sometimes also spelt 'computor'. At that time, this word just meant someone who computed or calculated.

Since his work involved a great deal of mathematics, Radhanath was eager to learn more. He had already devoured every math book available at his school. But in those days, there were hardly any colleges or institutes offering higher mathematics, so he had to teach himself. In his diary, he wrote quite blandly, 'I started studying many other books on Mathematics.'

He didn't stop there—he also immersed himself in the study of geodesy. His dedication didn't go unnoticed. Even Everest remarked, 'There are few in India, whether European or native, that can at all compete with him.' It wasn't long before Radhanath's prodigious mathematical ability earned him a transfer to the GTS office in Dehradun.

Eighteen years later, he was transferred back to the Survey of India office in Calcutta and put in charge of the computing section. As Chief Computer, Radhanath had to make sense of the humongous amounts of raw and often confused data that field teams of surveyors were sending in. In fact, there was a backlog of several years he had to deal with.

In the middle of all this computation work, Radhanath wrote parts of the book *A Manual of Surveying for India,* authored by Ralph Smyth and Henry Thuillier, who later became Surveyor General of India. In their preface, they acknowledge that large parts of the book were written by 'the distinguished head of the computing Department of the GTS of India'. Thuillier and Smyth then use a lot of big words of praise to essentially say that they couldn't have written the book without him. Radhanath also published a book titled, *A Set of Tables for Facilitating the Computation of Trigonometrical Survey and the Projection of Maps for India.*

In 1853, Radhanath became the first Indian to be elected a Fellow of the prestigious Royal Astronomical Society in London. However, he is best remembered for his role in calculating that Peak XV—later named Mount Everest—was, in fact, the tallest peak in the world.

Radhanath Sikdar died on 17 May 1870.

THE REACTIONS OF THE PEOPLE OF INDIA TO THE GTS

For some, the Survey was a scientific endeavour. For others, it was a way to map a territory in order to understand and rule it more efficiently. But try thinking of it from the point of view of an average Indian back then.

Here they were, living peacefully in their villages, largely untouched by the wheeling and dealing of the East India Company, when suddenly, an unfamiliar force descended upon them—what looked like an army. Worse still, among them were the ruling British.

Anything the surveyors did, anything they said, would have been met with suspicion. Naturally, the local people pushed back. They caused trouble. They laid obstacles. Sometimes they trashed and destroyed Survey property. They withheld information, doing everything in their power to protect their land and way of life.

There were many reasons for their wariness.

The Great Trigonometrical Survey bore a striking resemblance to reconnaissance—an exploration of land before an attack or invasion. Also for years, the British had conducted surveys to assess the land and determine its revenue potential. These surveys were invariably followed by taxation. The people had observed the pattern and, understandably, were wary of this one as well.

Most people simply didn't believe it when the surveyors said they were making maps. This is not how one made maps, was it? One walked the roads with paper and pencils, not sat on hilltops and fiddled about with machines and flares and whatnot. And if they were making maps, why weren't they asking local people for directions? Incidentally, this reaction was not very different from a British official in Madras who had objected to Lambton's proposal for a trigonometrical survey. 'If I wish to proceed to Seringapatam,' he had said, 'I have only to tell the palanquin bearers, and they will find their way to it just as well as if it were ever so accurately placed on the maps.'

The surveyors used flags as signals to mark points. Flags are a common symbol of authority, and when the surveyors flew them from hilltops, rumours of an impending invasion began to spread. Even if a local king was sympathetic towards the survey, he wouldn't be happy with the surveyors' flags flying from his fortress walls—it would have appeared as though he had, even temporarily, surrendered his authority to the British. Such a display would have been a blow to his dignity, potentially making him seem weak in the eyes of his subjects.

Lambton even offered to put up flags that had no significance or importance, but it didn't make much of a difference. Finally, the surveyors resorted to using other innocuous things instead, like a strong plant, or a basket on top of a pole.

Hilltops were commonly places where temples or other religious structures were built to honour local deities. The sight of strangers stomping about these sacred spaces was deeply disturbing to the local people and seen as an act of disrespect towards their gods.

Night signals brought their own set of problems. A bunch of people huddling at night working on unfathomable things using strange instruments, and fires and signals at night? It had to be something supernatural, or maybe they were communicating with dark forces! It was unsettling, even frightening.

One king was so alarmed that he sent a drum-beating messenger through his kingdom to warn his subjects to keep their children away from the surveyors—or risk them being burnt in the signal fires.

On the other hand, some locals believed that the posts and even the Great Theodolite were divine objects and began offering prayers to them. But when their prayers went unanswered, frustration turned into hostility, and they took out their anger on both the instruments and the surveyors, causing significant damage.

Some local nobles were worried and outraged that some observation posts seemed to overlook the *zenanas*, the private residences of women. Naturally, they assumed this was an attempt to spy on them. Adding to their suspicions was a widespread belief that these instruments turned the images of humans upside down. And why, they wondered, would someone want to turn a woman upside down if not for indecent purposes?

Then there was the outrage caused by the clearing of land to ensure unobstructed lines of sight. Beloved old trees were sometimes cut down, and in more extreme cases, entire houses, or even villages, were razed. To say this caused hurt feelings would be an understatement. At one point, near Dehradun, Everest had to demolish 100 houses in a village, forcing the residents to leave their homes in the dead of winter. Although the Survey compensated them for their trouble, the fact remained: they had lost their homes.

Surveying required a great deal of labour. Beyond those who travelled with the surveyors, the Survey frequently hired local people to build roads to hilltops, clear away trees, or hoist flags. They also depended on nearby villages for essential resources, such as food and commodities. While the villagers were paid for their services, this work often took them away from their regular livelihoods. When such demands clashed with the agricultural calendar, it led to grumbling and ruffled feathers in the surrounding communities.

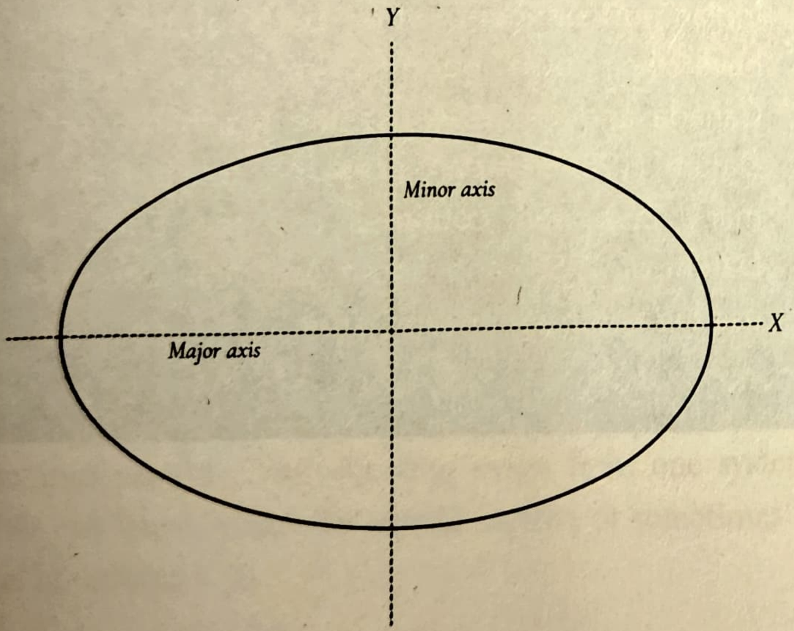
While we may admire and applaud a project of this scale, one that was so significant to the history of science and cartography, it is equally important to acknowledge the human costs of such an endeavour.

THE GTS TODAY

HOW IS THE GTS RELEVANT TO US TODAY?

THE EVEREST SPHEROID

An ellipse is a regular oval shape. It has a longer major axis and a shorter minor axis.


Y
Minor axis
X
Major axis

An ellipsoid or a spheroid is the three-dimensional version of an ellipse—somewhat egg-shaped. (You get a spheroid when an ellipse is rotated around one of its axes.) The ellipsoid or spheroid also has a major and minor axis. (The same as its corresponding ellipse.)

If you know the lengths of the major and minor axes, you can construct an ellipse, and by extension, an ellipsoid or spheroid.

The mapping of India and the Great Arc gave us valuable information about the shape of the Earth over the surface of India, as we have already seen. Everest calculated the major and minor axes of a spheroid that best represents what the surface of the Earth is actually like in the Indian subcontinent. This set of figures is called the Everest Spheroid or, sometimes, the Everest ellipsoid. The Everest Spheroid is also called the geodetic reference datum of India.

Just as we have the Everest Spheroid for the Indian subcontinent, other parts of the world have their own geodetic reference datums. Canada and the USA use the North American Datum (1983), Japan uses the Tokyo Datum, many European countries use the European Datum of 1950, and South American countries use the South American Datum.

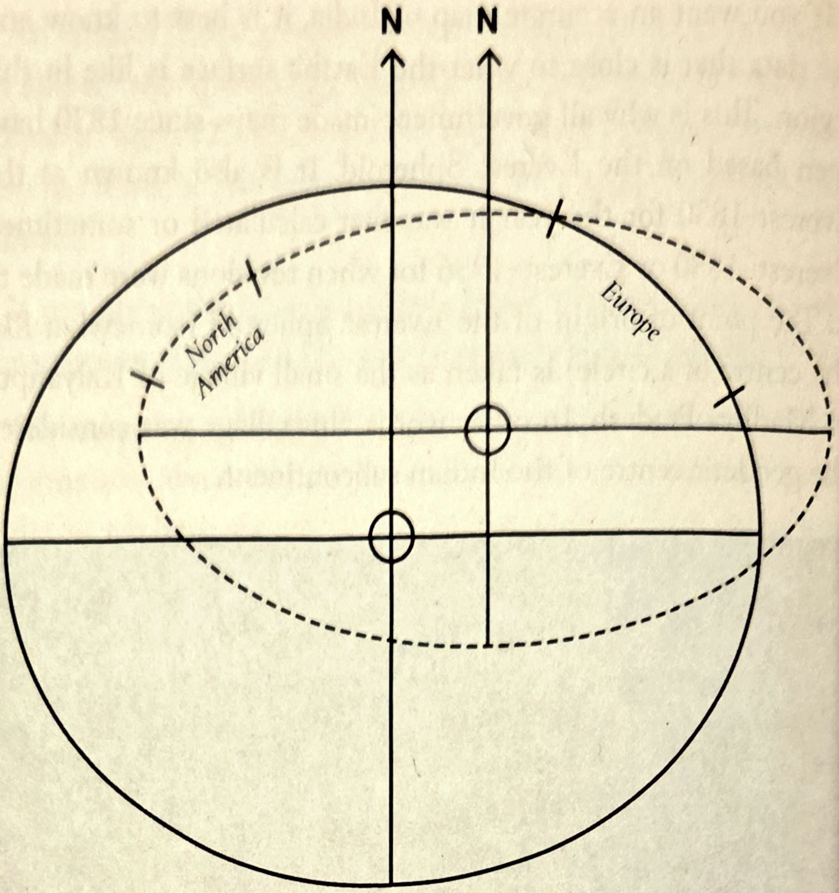
If you want an accurate map of India, it is best to know and use data that is close to what the Earth's surface is like in this region. This is why all government-made maps since 1830 have been based on the Everest Spheroid. It is also known as the Everest-1830 for the year it was first calculated or sometimes, Everest–1880 or Everest–1956 for when revisions were made to it. The point of origin of the Everest Spheroid (somewhat like the centre of a circle) is taken as the small village of Kalyanpur in Madhya Pradesh. In other words, this village was considered the geodetic centre of the Indian subcontinent.

Kalyanpur's coordinates are 24°07'11.3"N 77°39'00.6"E.

Do you know the coordinates of the place you live in?

But hang on, you say. Nowadays, we use satellites and GPS to make maps. We don't need to mess about with datums from the 1800s.

Well, yes and no. Sure, more of the world is using GPS for making maps. Maps like the ones we use on our cellphones, for example, are made with GPS. But many military maps around the world are still made with location-specific datums like the Everest Spheroid. Mathematicians and geographers have worked out the maths needed to transform maps from one datum into another. Transforming maps from one system to another can 'move' places by several metres, or sometimes even several kilometres!



A spheroid that fits well in Europe may not be appropriate for North America and vice versa.

• TECTONIC SHIFTS •

Moving from one map system to another might 'move' things theoretically. But places can actually move on the ground, too. If you've ever experienced windows rattling for a few seconds, ceiling fans swinging wildly, or things falling off a shelf, it's probably not a poltergeist. It's most certainly an earthquake. Earthquakes happen because the tectonic plates that make up the Earth's crust are constantly moving. Because the GTS benchmarks and baselines were made and measured with such accuracy, they provide useful points to geologists who study earthquakes and plate tectonics.

BENCHMARK is a permanent reference mark, often carved into a wall, building, or milestone, indicating a precisely measured altitude. Used by surveyors as a fixed point for elevation and mapping purposes..

ALTITUDE is the height of a place above sea level.

Some years ago, scientists re-measured the Bangalore and Kanyakumari baselines, originally surveyed in the 1860s, to study continental drift. Their findings revealed that the region around Bangalore shifts approximately 4–5 cm north and east every year! Similarly, after the devastating Bhuj earthquake in Gujarat in 2001, scientists used GTS stations to calculate how much towns and villages had been displaced by the seismic event.

WHAT CAN YOU SEE OF THE GTS IN INDIA TODAY?

The Great Trigonometrical Survey was one of the most ambitious scientific projects of its time. For over eighty years, surveyors climbed mountains, established baselines and stations, and built towers across the subcontinent. Given that the project concluded more than a hundred years ago, one might assume that no physical traces of it remain. But surprisingly, remnants of the GTS still exist, scattered across India—perhaps even near where you live!

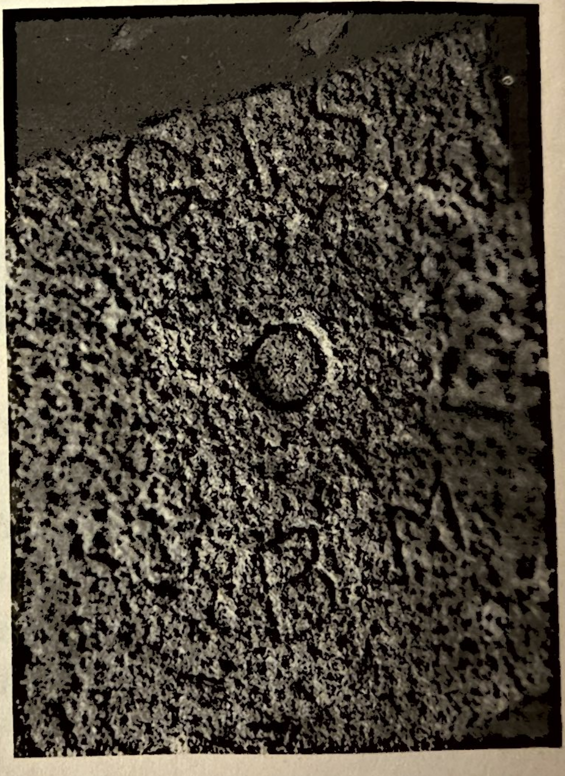
• CIRCLES AND LETTERS •

The GTS benchmarks, chiselled into rocks, buildings, and other structures, can still be found throughout the country. These markers indicated locations where surveyors had carefully measured or calculated exact elevations above mean sea level, for the benefit of future surveyors and engineers.

The benchmarks come in different forms. A common type features the letters GTS in capitals, a small circle below them, and the letters BM (for Benchmark) beneath the circle. Some have a square instead of a circle, while others include an arrow mark. In certain locations, benchmarks were inscribed on specially erected stone pillars, sometimes labelled 'GTS Standard Bench Mark' along with the year of installation. You can see such small pillars in many places around India, such as Nagpur, Ahmedabad, Hinganghat and Faizabad, for example.

If the year isn't mentioned, it is very difficult to determine when the benchmark was measured and recorded. It could date from anytime between the early 1800s and the early 1900s.

The surveyors put these benchmarks on buildings



A benchmark on an old streetside water trough in Bangalore and structures that they thought would last a very, very long time, if not forever. Unfortunately, though, many did not survive even fifty years. But there are still quite a few left. Here are some places where we have found small GTS benchmarks chiselled: the pedestals of old statues; sluice gates on irrigation channels; steps leading to old temples; steps at the entrances of old churches; and near the toilets on railway station platforms! Keep a look out: maybe you'll find one in an unexpected place near you!

Happy sleuthing!

• BASELINES AND OTHER STATIONS •

The baselines and principal triangulation points, painstakingly set up across the country, were carefully marked for future use.

FUN FACT: The ends of the first baseline of the first trigonometrical survey in England, conducted in 1791, were marked with cannons driven upright into the ground so that only their muzzles were visible. In India, however, you will need to look for more mundane markers—such as platforms, pillars and towers.

In the early years of the survey, the ends of baselines were marked with pillars raised on platforms. Three decades later, surveyors observed that Nature often reclaimed these platforms, rendering them almost untraceable. So, when they established new baselines or remeasured old ones, they built larger and more permanent structures to mark the ends.

In Kolkata, the ends of the baseline were marked by square towers, each about as tall as a seven-storey building. Both towers still stand on Barrackpore Trunk Road (better known as BT Road), each with a line painted on them explaining that they are part of the GTS. However, for some years, one of these towers was famously known to Kolkatans as the Boroline Tower—because it sported an advertisement for that cream!

Most other baselines in the country were marked with incredibly complex structures designed to protect the measurement points against all odds. In many cases, the actual measurement point was a small lead dot embedded in a brass plug or a small brass dot set into stone. This was typically fitted into a stone block and buried a few feet underground. Surveyors then built towers or small brick or stone buildings over them.

These buildings often had a circular pit directly above the buried measurement point. The pit was meant to hold a pillar, which would have supported the theodolite during measurements. If you ever came across one of these unusual-looking structures, you might be puzzled by its shape—but you would not immediately realise that a crucial markstone or measurement point lay hidden beneath it.

Today, many GTS observatories and towers have been lost. In Bengaluru, for example, the observatory at the southwestern end of the Bangalore baseline was demolished years ago. Only a small square platform still marks the exact endpoint of the baseline. If you're in the area, you can find it next to the Kempegowda Tower on Bellary Road—and while you're there, see if you can spot the benchmarks on the tower's steps!

The observatory at the northeastern end of the Bangalore baseline was vandalised and razed in June 2024, even as this book was being written. The demolition shocked and dismayed Bengalureans. Now, the government of Karnataka, citizens and organisations like the Indian National Trust for Art and Cultural Heritage are trying to work towards rebuilding the lost observatory.

When establishing a baseline, there were usually several observation points associated with it which were made to minimise observation and calculation errors. These points were called intermediate or auxiliary stations. They were usually marked with pillars on platforms. You can still see a partially destroyed platform with a pit indicating where the pillar would have been at Sampigehalli near Jakkur, in Bangalore.

Many of the hills around Bangalore were principal stations for triangulation and were marked with pillars and platforms. You can still see the remains of a platform, but no pillar, at Savanadurga.

From 1802 to 1885, the GTS established more than 3,600 principal stations. No doubt there are remains of pillars and platforms all around the country, still waiting to be found. Maybe you'll be the one to find some of them!

• 'ZERO MILE' STONES •

Many cities in India have 'zero mile' stones. These were markers to indicate the spot at which you begin measuring distances to other places. In most places, this 'zero' spot is the General Post Office. In Pune, for example, you can see the zero milestone on Sadhu Vaswani Path, just outside the General Post Office. Near this, there is some signage that has been recently installed, which talks about the GTS and some of its prominent men. Of course, for you GTS pros who have read this book, the information will be stuff you already know!

You may also have heard about or perhaps seen the Zero Mile Stone in Nagpur. This is popularly said to have been installed as part of the GTS. There is indeed a GTS benchmark near the pillar indicating the elevation at the point. However, there is no evidence linking the Zero Mile pillar itself to the GTS.

• A BASELINE AND A BUST IN CHENNAI •

The Madras Race Course, now known as the Madras Race Club, where the north end of the first official GTS baseline was, still exists. Carry a pair of binoculars or perhaps a telescope if you have one when you visit, and see if you can sight St Thomas Mount and Perumbakkam Hill from there. It might also be exciting to use a cellphone to see what the latitude at the Race Course's grandstand is. Do you think it will exactly match what Lambton had noted, 13°0'29.59" N? Why or why not?

Next, head over to St Thomas Mount (Parangimalai in Tamil), which is named after the apostle St Thomas, who is said to have lived and prayed here in the first century CE. There is a sixteenth-century church on the summit of this hillock. A little behind the church, there is a bust of Col William Lambton. The plaque says that Lambton began the fieldwork for the GTS from that point. Now that you've read this book, you know that that is not entirely correct, but there's no denying that St Thomas Mount was indeed one of the first principal stations of the GTS.

• A PORTRAIT IN THANJAVUR •

While surveying in the plains of Tamil Nadu, there were no convenient hills where Lambton could establish trig points.

But there were lots of temples with tall gopuras, the sculptured entrance towers that most mediaeval South Indian temples have. Gopuras had made convenient points for sighting even during the trial near and around Bangalore. The team continued using gopuras in Tamil Nadu.

When they arrived in Thanjavur, the tallest structure here was not the entrance tower but the immense *vimana*, the tower over the sanctum of the magnificent Brihadishwara temple. The temple was almost 800 years old when Lambton visited. Its tower is built entirely of stone and is close to 60 metres tall, as tall as a twenty-storey building. The height made it the perfect spot for sighting for the GTS. With the permission of the priests, Lambton had the Great Theodolite hauled up the temple tower with ropes and pulleys. The instrument made its way slowly and jerkily to the top. Suddenly, the rope snapped. Crash! The Great Theodolite smashed into the stone tower and thudded to the ground.

Thankfully the theodolite was in its box, and so it wasn't completely shattered. But it was severely damaged. For six weeks, Lambton shut himself up in a tent with the injured theodolite and worked night and day in sweltering heat until he returned it to working order.

As for the 798-year-old stone tower, it too was damaged. The next time you visit the Brihadishwara temple, look at the northern side of the tower. About halfway up, nestled between sculptures of the celestials, you can spot the distinctly out-of-place figure of a chap wearing a European hat and coat, arms crossed and appearing to look out a window. It is popularly believed this was the sculpture Lambton had installed here to repair a damaged one. Do you think the sculpture shows a surveyor?

• THE GTS TOWERS •

The GTS in south India hopped from hill to hill, and temple to temple. But we've seen how this was not possible in the plains of northern India and how the surveyors sometimes made use of the old towers of the so-called visual telegraph. The short towers built for this system of messaging were abandoned in 1830. But since the telegraph towers were not always where the GTS wanted them, the GTS surveyors also built brick towers. In Everest's time, fourteen of these towers were built. Some were adaptations of old existing telegraph towers, others were newly built. They were between 40 and 60 feet tall (about 12 to 18 metres), built of brick. Most towers were square at the base and tapered to a flat, square top. All are hollow and have narrow, small windows at every level. The all-important measurement mark will lie buried below the floor or sometimes, level with the floor.

You can still see many of these towers especially near Kolkata. For instance, at Nibra near Howrah, you can see a visual telegraph tower that was modified a little and used for the GTS. In Bhola, a village close to Singur, you can see a square tower, somewhat dilapidated, of what some people call the 'Everest type.' Some are only remnants of towers; some have vines creeping up over them. Be careful when you go exploring. Not all towers will be stable.

• THE HOME OF A COLOSSUS IN MUSSOORIE •

About 6 kilometres to the west of the Himalayan town of Mussoorie is a relic that is intimately connected with the GTS. In the village called Hathipaon, you will find Park House, the much-loved home of George Everest from 1832 till his retirement in 1843. Park House was built about two years before Everest bought it from the first owner. He moved there in 1832 and planned to set up a home office there. When he first moved in, the house was rather isolated. Everest got a path built, with access from the main roads. He also got permission from the government to set up a small observatory and workshop in the premises. (This was where Mohsin, the jeweller-turned-instrument-engineer from Arcot, worked on the astronomical circles.) Everest also added a couple of other buildings which were called Bachelor's Hall and, rather unusually, Logarithm Lodge. When he retired, Everest sold Park House, which then changed hands several times until the state government finally bought it about fifty years ago. It lay in ruins, full of weeds, graffiti and cow droppings until it was renovated in 2020–21.

Bachelor's Hall and Logarithm Lodge both no longer exist. Only part of the original house, the observatory and some quarters still stand. Built on a spur that is about 2,160 metres above sea level, Park House in Hathipaon has spectacular views of the Doon Valley and of snow-capped Himalayan peaks, though not the one named after Hathipaon's most famous inhabitant.

• A MUSEUM IN DEHRADUN •

Wouldn't it have been fun to see the theodolite that Lambton used, that huge telescope that weighed half a tonne, travelled across the seas, got stuck on the way to India, had to be carried up and down hills, and fell down from a temple? Guess what, you can! Head to the Survey of India's museum in Dehradun, which has a fascinating collection of compasses, sextants, spirit levels, chains and, of course, theodolites, including Lambton's. The museum has other interesting exhibits on the history and evolution of surveying in India, including the GTS and other kinds of surveys.

• LAMBTON'S FINAL RESTING PLACE NEAR NAGPUR •

In January 1823, Lambton was heading off to work on another baseline when he fell ill and died at Hinganghat, a small town near Wardha in Maharashtra. Archival records indicate that, at Everest's suggestion, 'a worthy monument' was erected to mark his grave. We also know that until the 1920s, the grave was being tended to.

Sometime in the 1990s, the British historian and acclaimed author John Keay visited Hinganghat looking for William Lambton's grave. In his book on the GTS, Keay describes finding a rather plain, flat grave with an outline of a casket on it. Finding the letters L, A, M, B crudely written in the mortar, Keay concluded that it was Lambton's grave.

Keay had also seen a grave which was locally called the Belgian's Stone. He dismissed this as not being Lambton's grave. However, based on descriptions of the grave being close to a water tank and also close to a standard benchmark, both of which are still there, this memorial could also very well be Lambton's grave. It also tallies well with the description of 'a worthy monument' being raised at his grave. And yet, the letters Keay found on the nondescript grave suggest that *that* is Lambton's grave. How can we be sure of the great surveyor's final resting place?

The self-effacing genius who never much liked to talk about himself and was so elusive in life remains so in death.

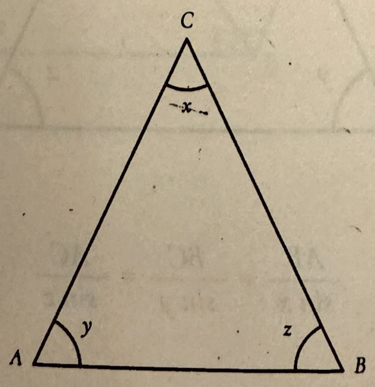
ACTIVITIES

DO YOUR OWN TRIANGULATION SURVEY

What you need: Protractor, ruler, a pencil if you're working on paper, or chalk or floor marker if you're working on the floor or a field.

Select a piece of land, which could be a bit of ground anywhere you please—a park, the floor of your house, your desk, or even a piece of paper if you like.

1) Select a straight baseline and carefully measure its length using a ruler or a measuring tape. Let's call this baseline AB. The accuracy of this measurement is important, as all other calculations will depend on it.



2) Choose a third point C at some distance from the baseline. This is the point you will need to sight from both ends of your baseline—points A and B.

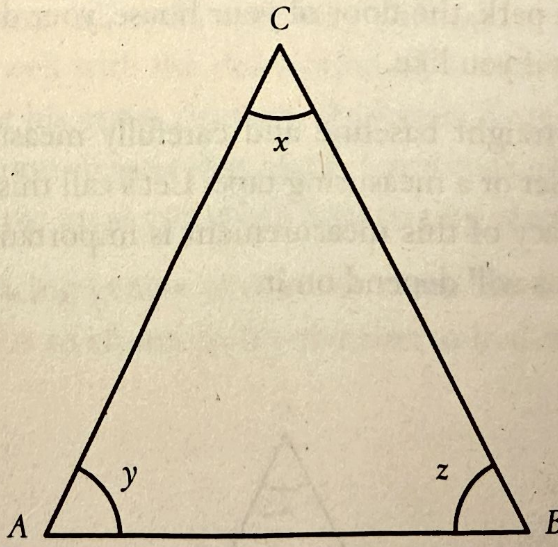
3) In real land surveys, surveyors cannot physically draw lines connecting A to C and B to C. They rely on sighting the points using a theodolite. However, since this is a simplified version, you can draw the lines AC and BC on paper or mentally visualise them if you are working outdoors.

4) Since we don't have a theodolite, we'll have to measure angles using a protractor. So measure out angles CAB (Angle y) and ABC (Angle z)

5) Now, we can find the lengths of AC and BC using trigonometry (without needing to measure it with a ruler or a measuring tape.)

Here's how you do it:

The formula is:



$$\frac{AB}{\sin x} = \frac{BC}{\sin y} = \frac{AC}{\sin z}$$

6) Now you have the length of AC and BC. Make BC your secondary baseline. D is now your new sighting point.

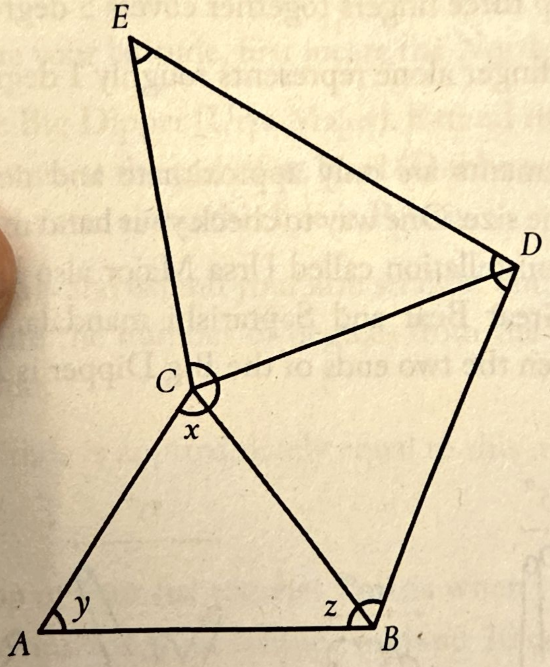
Repeat the same thing, and find the lengths of CD and BD using the same formula [Length of side1/sin (opposite angle) = Length of side 2/sin (opposite angle) = Length of side 3/ sin(opposite angle)]

7) Make CD your secondary baseline.

E will now be your sighting point.

Now you can calculate the length of CE and DE.

Now you can measure DE using your ruler and see if the value you get is the same as the value you got from trigonometry!

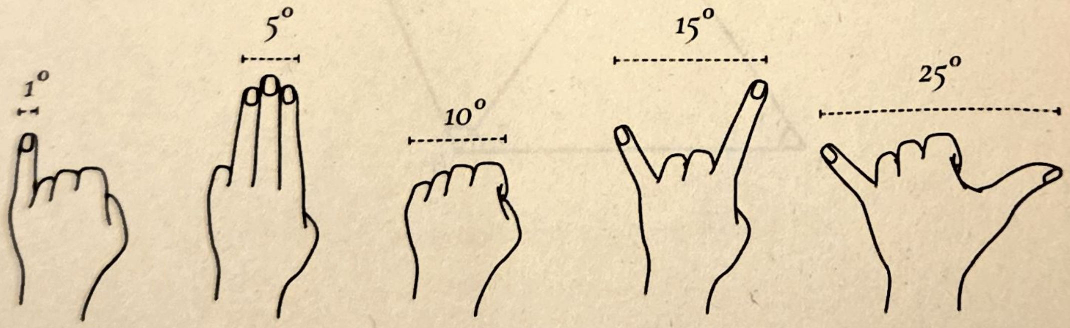


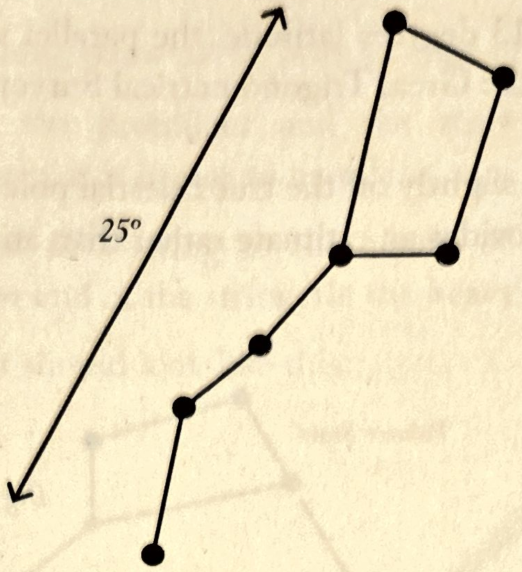
USE YOUR HANDS TO FIND YOUR LATITUDE

You are going to use the stars to measure your latitude. Astronomers use angular measurements for the apparent distances between stars in the night sky. You are going to measure the angular distance in degrees using your hand.

1. Hold out your hand and spread your fingers wide—the distance between the tip of your little finger and the tip of your thumb is approximately 25 degrees.
2. The span from your index finger to your little finger is about fifteen degrees.
3. A clenched fist measures about 10 degrees.
4. Holding up three fingers together covers 5 degrees.
5. Your little finger alone represents roughly 1 degree.

These measurements are only approximate and not everyone's hand is the same size. One way to check your hand measurements is to use the constellation called Ursa Major also known as the Big Dipper, Great Bear and Saptarishi mandala. The angular distance between the two ends of the Big Dipper is 25 degrees.





Big Dipper

To determine your latitude, first locate the North Star (Polaris).

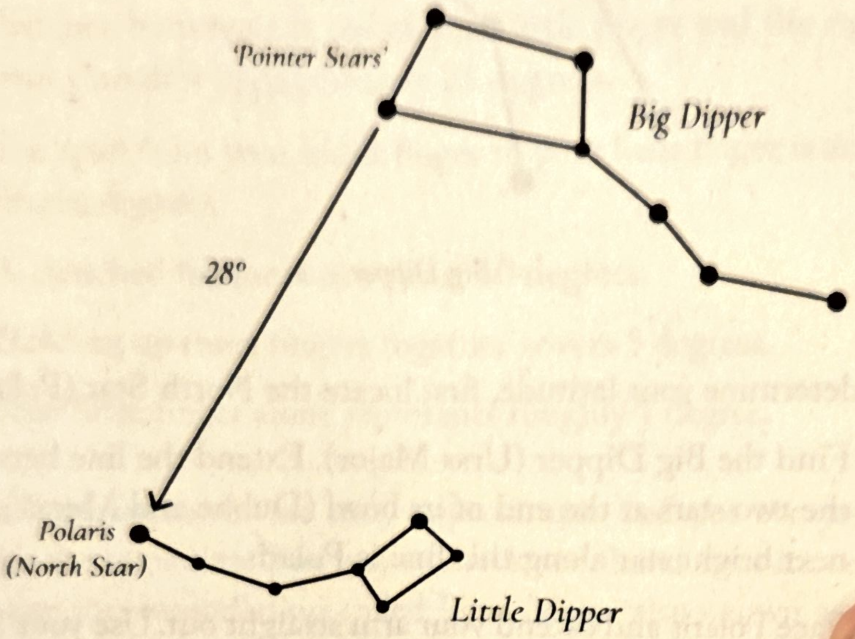
1. Find the Big Dipper (Ursa Major). Extend the line between the two stars at the end of its bowl (Dubhe and Merak). The next bright star along this line is Polaris.
2. Face Polaris and extend your arm straight out. Use your hand to measure the number of degrees from the horizon to the North Star.
3. Your latitude is approximately equal to this measured angle.

For example:

- If the top of your fist touches Polaris when your little finger is on the horizon, your latitude is about 10 degrees.
- If you need to stack two fists to measure from the horizon to Polaris, your latitude is around 20 degrees.
- If you use a fist and you need to measure with the little finger of your other hand three times (so, 10 degrees + 3 x 1 degree)

to measure the distance from the horizon to the North Star, you are at 13 degrees latitude, the parallel where Lambton started off the Great Trigonometrical Survey!

Since Polaris is slightly off the true celestial pole (by about 0.7°), this method provides an estimate rather than an exact latitude.



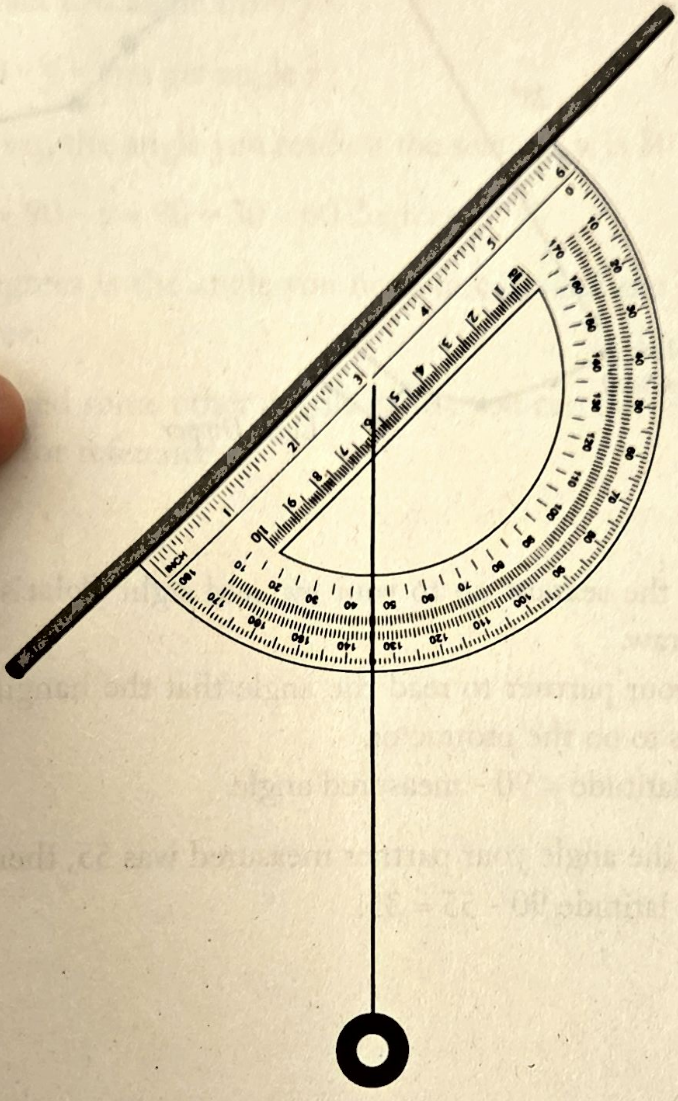
HOW TO FIND YOUR LATITUDE USING A SEXTANT

The first step is to make your own sextant.

The materials you'll need are a protractor, a drinking straw, construction paper, string, and sticking tape. You'll also need something a little heavy to weigh the string down, like a heavy screw or a coin.

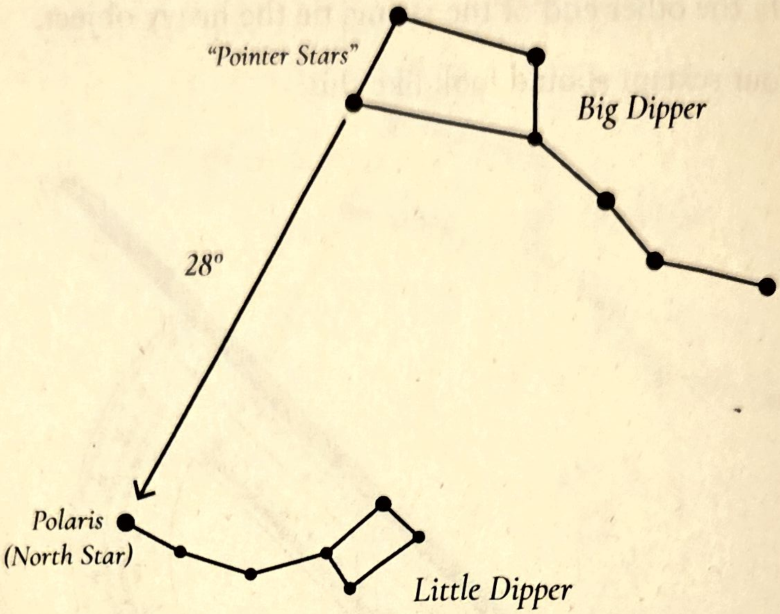
To make a sextant,

- Tape a drinking straw to the bottom edge of a protractor.
- Paste both the protractor and the straw onto a thick cardboard so that it is easy to handle.
- Tie one end of a string to the centre of the protractor. On the other end of the string, tie the heavy object.
- Your sextant should look like this:



Now that you have your own sextant, let's measure the latitude of your location.

- On a clear night, find Polaris in the sky, as explained in the previous section.


"Pointer Stars"
Big Dipper
28°
Polaris
(North Star)
Little Dipper

- Hold the sextant up to your eye and sight Polaris through the straw.
- Get your partner to read the angle that the hanging string points to on the protractor.
- Your latitude = 90 - measured angle.
- So, if the angle your partner measured was 55, then you are at the latitude 90 - 55 = 35!

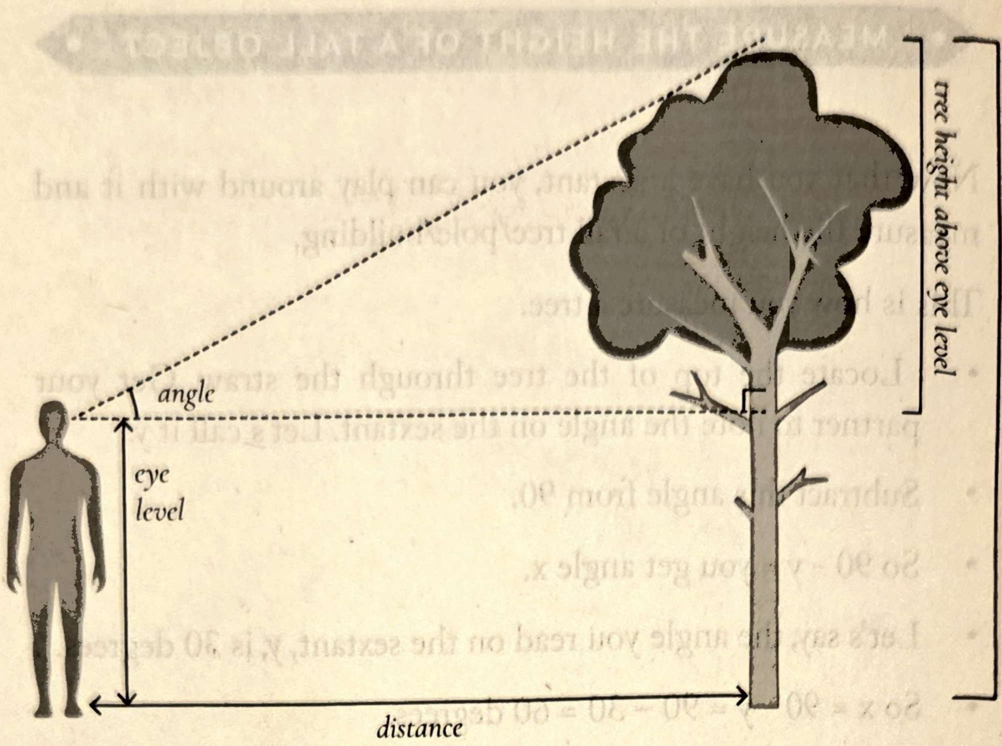
MEASURE THE HEIGHT OF A TALL OBJECT

Now that you have a sextant, you can play around with it and measure the height of a tall tree/pole/building.

This is how you measure a tree.

- Locate the top of the tree through the straw. Get your partner to note the angle on the sextant. Let's call it y.
- Subtract this angle from 90.
- So 90 - y = you get angle x.
- Let's say, the angle you read on the sextant, y, is 30 degrees.
- So x = 90 - y = 90 – 30 = 60 degrees.
- 60 degrees is the angle you need to calculate the height of the tree.

You also need some other details before you can do this. Check this figure for reference:



tree height above eye level = distance × tan(angle)
tree height = eye level + tree height above eye level

Tree Height Diagram

- You need your own height, or rather, the height of your eye from the ground. Let's say your eye is at 150 centimetres above the ground.
- You also need the distance at which you are standing from the tree. Let's say you are standing 300 centimetres away from the tree
- So, first, you calculate the height of the tree above your eye level, as in the diagram.
- Tree height above eye level – distance x tan(angle)
- In this example, tree height above eye level = 300 x tan 60 = 519.6 centimetres.

- Tree height = your eyelevel height + tree height above eye level

= 150 + 519.6

= 669.6 centimetres = 6.7 metres

HOW TO MARK GEOGRAPHICAL NORTH LINE DURING DAYTIME

Items needed:

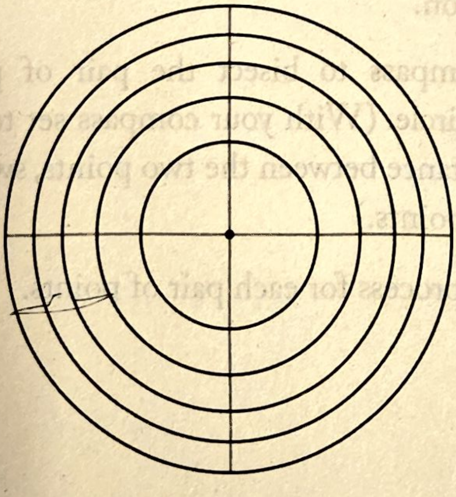
A3 or A4 sized papers

A thick cardboard sheet to glue the paper on

pencil (7 to 10 centimetres in height or any cylindrical object with a sharp tip), sharpener, eraser, ruler, compass, glue stick, fine-tipped pen

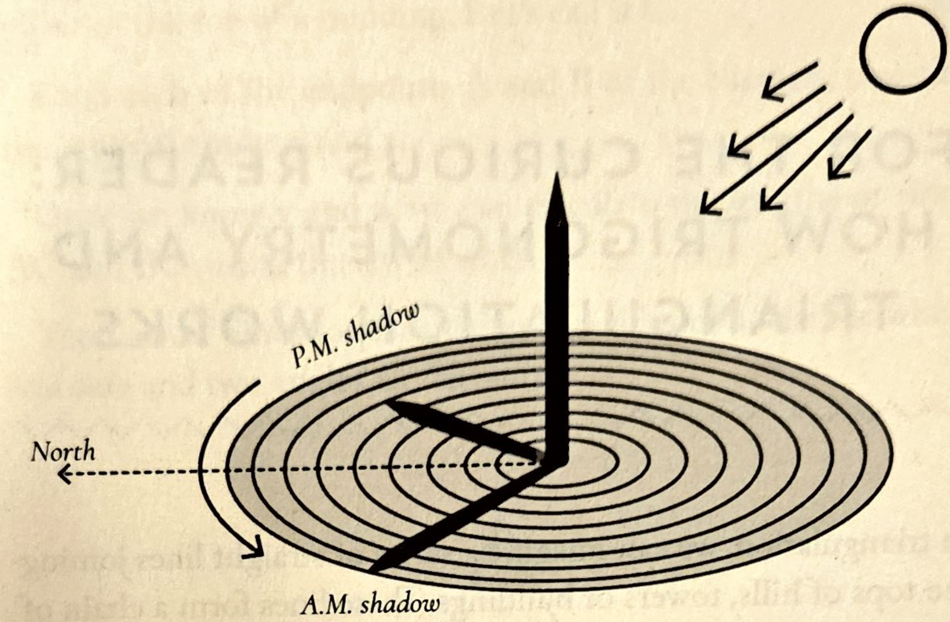
Procedure

1. Print or draw concentric circles on the paper. The radius need not be increasing identically.



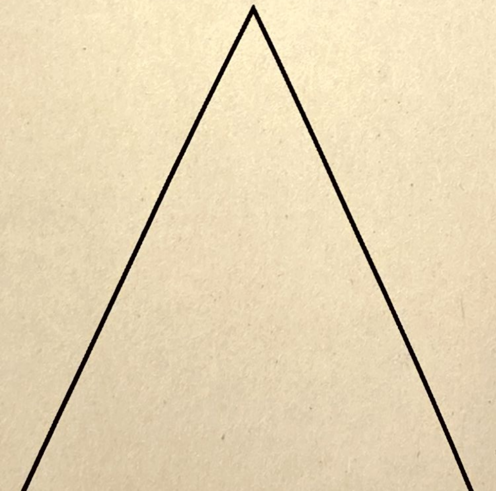
2. Stick this paper with concentric circles onto a thick cardboard sheet, so that it is easy to carry and place it on a flat surface.
3. Choose a bright and sunny day.
4. Choose a flat surface on the ground or a table open to the sky. Stick the cardboard (with concentric circles) to the flat surface. This should not move for the entire duration of the activity.
5. Fix the pencil (or the cylindrical object) exactly at the centre of the concentric circle, such that the sharp tip is facing upwards to the sky. The pencil should be as perpendicular to the flat surface as possible.
6. Start the activity well before noon, say 9 a.m. Observe the shadow of the tip of the pencil on the paper. When it touches one of the concentric circles, mark the point clearly.
7. Wait for the shadow of the tip to touch the next concentric circle. Note that this would be one of the inner circles as the sun moves up and the shadow gets shorter.
8. Repeat the process after noon too. So, on each concentric circle, there will be two points marked, one before noon and one after noon.
9. Use the compass to bisect the pair of points on each concentric circle. (With your compass set to approximately ¾ of the distance between the two points, swing an arc from each of the points.)
10. Repeat the process for each pair of points.

11. Draw a line to join all the intersecting points of the bisecting arcs.
12. This is the geographic North line!


P.M. shadow
North
A.M. shadow

FOR THE CURIOUS READER: HOW TRIGONOMETRY AND TRIANGULATION WORKS

In triangulation, we can imagine a series of straight lines joining the tops of hills, towers or buildings. These lines form a chain of interconnected triangles spread out over the area.

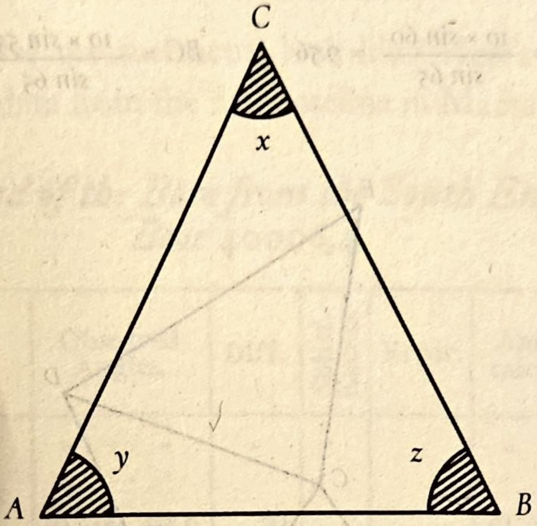


To begin with, choose a baseline, which makes up one side of the first triangle. You measure its length physically along the ground. This is the only time an actual physical measurement along the ground is necessary. Let's call this baseline AB. Next, we choose a visible point a distance away. It can be a hilltop or a tower or the top of a building. Let's call it C.

From each of the endpoints A and B of the baseline, measure the internal angles y and z.

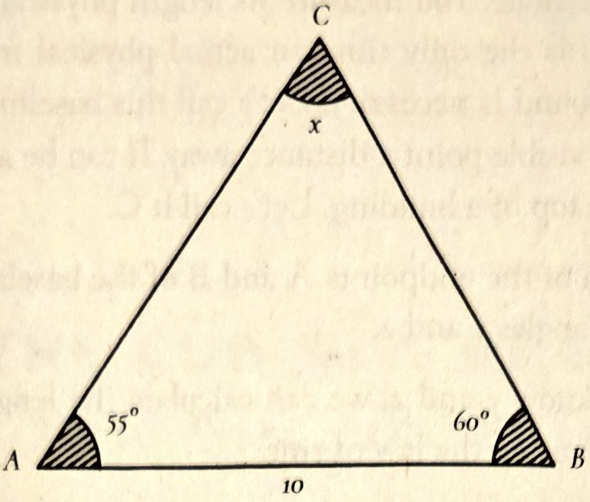
Once we know y and z, we can calculate the lengths of sides AC and BC using the law of sines.

The Law of Sines for calculating two sides of a triangle when one side and two angles are known:



$$\frac{AB}{\sin x} = \frac{BC}{\sin y} = \frac{AC}{\sin z}$$

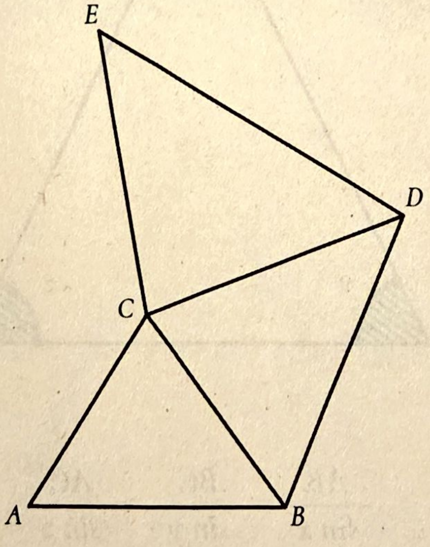
If you want to try this with actual numbers:



$$x = 180^\circ - (60^\circ + 55^\circ) = 65^\circ$$

$$\frac{10}{\sin 65} = \frac{AC}{\sin 60} \qquad \frac{BC}{\sin 55} = \frac{10}{\sin 65}$$

$$AC = \frac{10 \times \sin 60}{\sin 65} = 9.56 \qquad BC = \frac{10 \times \sin 55}{\sin 65} = 9.04$$



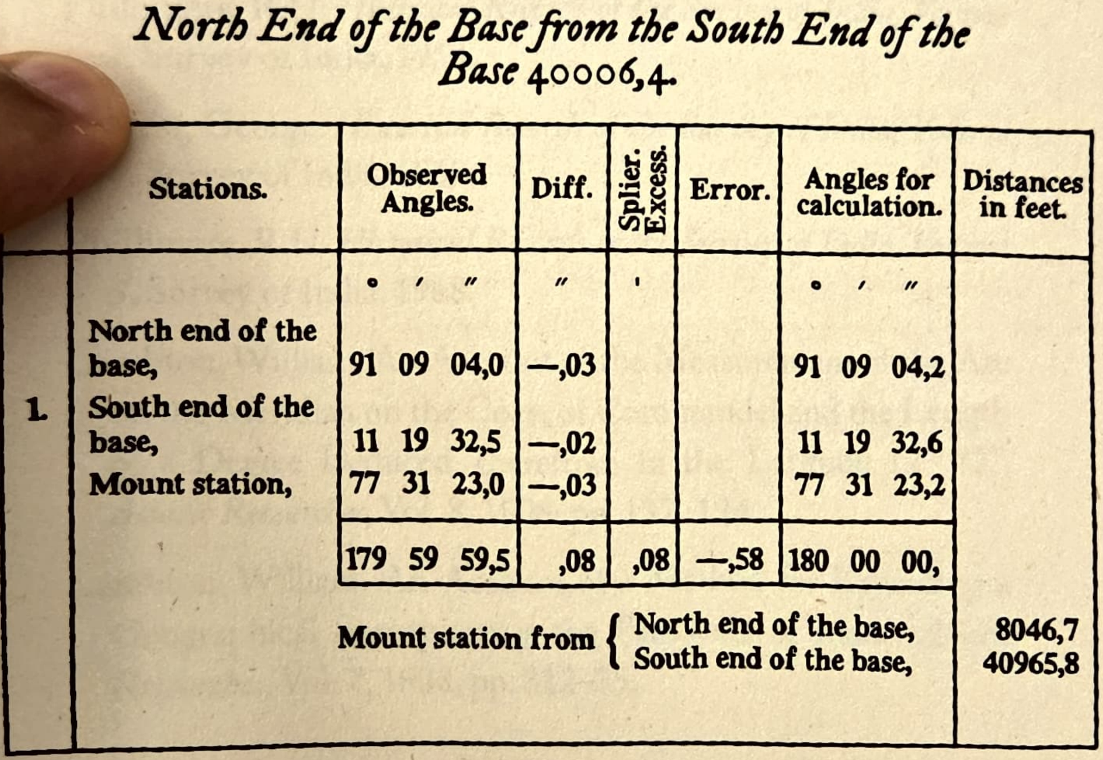
Now, you can use BC as a known length in the next triangle BCD, which means you can calculate CD and BD. Next, CD will become the known length for yet another triangle CDE, and so on.

Remember, the distances in all these secondary triangles aren't actually measured along the ground. You can calculate their lengths using mathematics.

In a trigonometrical survey, the size of the triangle can be massive. The lines can be several kilometres long. The size of the triangle is limited only by the line of sight between the endpoints of the baseline and the new point. These distances depend on how powerful the measuring instruments are, and whether the third point is visible (no obstructions should stand in the way, the day should be clear, and so on.)

The triangles need not even be symmetrical, but the more symmetrical they are, the better the accuracy.

What did these measurements look like? Here's an example from the GTS data from the first baseline in Madras.



North End of the Base from the South End of the Base 40006,4.

	Stations.	Observed Angles.	Diff.	Spher. Excess.	Error.	Angles for calculation.	Distances in feet.
		° ′ ″	″	′		° ′ ″	
	North end of the base,	91 09 04,0	—,03			91 09 04,2	
1.	South end of the base,	11 19 32,5	—,02			11 19 32,6	
	Mount station,	77 31 23,0	—,03			77 31 23,2	
		179 59 59,5	,08	,08	—,58	180 00 00,	
	Mount station from					North end of the base,	8046,7
						South end of the base,	40965,8